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ABSTRACT

Presented is a study which investigated the energy and resource dynamics of a semi-autonomous domestic system for 30 people. The investigation is organized on three levels: (1) developing a preliminary design and design parameters; (2) development and quantification of the energy and resource dynamics; and (3) designing a model to extrapolate general concepts and factors affecting energy and material resource use. Sections contained within the text cover: shelter, food production, organic wastes system, domestic energy and water use, and a summary and conclusions. (CS)

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COMMUNITY DESIGN FOR OPTIMAL ENERY AND RESOURCE UTILIZATION

SE 029 025

COMMUNITY DESIGN FOR OPTIMAL ENERGY AND RESOURCE UTILIZATION

Research supported by a grant from the National Science Foundation Student Originated Studies Program.

Prepared June 1974 - January 1975 by:

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Stephen Bilenky - January 1975

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GENERAL INTRODUCTION

There has been a growing interest in the concept of autonomous servicing of domestic systems on the family and community level.[1-13] This is in part based on the idea of reducing residential dependence on dwindling fuel and material resources, and on extensive service systems which are also dependent on non-renewable fuel and material resources and have high environmental impact. Interest in this "self-sufficient" concept is also based on the possible fruition of many social-personal goals and philosophies.[14-23,2,3,5,7,8,9,10,12] All of these proposed systems have similar characteristics and goals:

1) Minimizing inputs of energy and material resources.
2) Development of on-site renewable and/or recyclable sources of energy, water, and materials.
3) Maximizing on-site food production.
4) On-site recycling and utilization of wastes.
5) Utilization of long-lived and recycled materials in constructions.
6) Same degree of lifestyle modification to achieve the above goals.

This project is a study of a domestic system which would have the above-mentioned characteristics. The project's goal was to investigate the energy and resource dynamics of a semi-autonomous living unit for thirty people. The investigation is organized on three levels: 1) developing a preliminary design and design parameters for a student-faculty, integrated environmental studies center for the Pennsylvania State University;

2) further development and quantification of the energy and resource dynamics of semi-autonomous, domestic systems; 3) utilizing the design process and parameters of a semi-autonomous domestic system as a model to extrapolate some general concepts and factors affecting energy and material resources use.

The first level involves the design of a student-faculty, living-learning center. This proposed center would be used for studying the various ecological, sociological, psychological, and technological aspects of contemporary environmental problems, as they interact in a whole system. A "micro-system," such as described in this report would be very useful for this kind of study: the students and faculty would be living, working, and researching in a system where all the interacting factors would be easily apparent in their immediate environment, rather than dispersed throughout some larger system. It would also allow for first-hand practical experience with the everyday tools, skills, technologies, and problems associated with the various aspects of our support systems (shelter, food, energy, waste, social, psychological, etc.).

On the level of the actual design, the services investigated were: shelter and environmental control, food production, storage and consumption, organic wastes system, water use, domestic energy use. Our main design goal was to design these service systems so as to require the least amount of outside inputs. The following strategies were utilized to achieve this goal:

1) Designing all the services as one functional system so as to maximize multiple-use of resources.
2) Minimizing per capita demands on the service systems, while maintaining an adequate living standard.
3) Utilizing required resources as efficiently as possible.

4) Satisfying the majority of resource needs from local, renewable and/or recyclable sources.

5) Utilizing existing biological and physical conditions as an integral part of the system's function and expression.

The design presented in this paper is only one set of alternatives which could be utilized to achieve the design goals. Other systems and combinations were omitted because of lack of information and/or time.

On the third level, the design presented is not to be viewed as the most efficient system possible, but as a model which illustrates basic dynamics and interactions of the systems utilized, and some of the major factors governing energy and resource utilization.

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SECTION I - SHELTER

I. INTRODUCTION

A. The shelter section of this project had several objectives. Primarily, our goal was to investigate the design and analysis of a shelter for thirty people that would be autonomous in its operating energy requirements. Secondly, we wished to investigate the utilization of:
1) Labor intensive rather than energy intensive building materials,
2) Local, long-lived and/or recycled or renewable resources, and
3) Low environmental impact energy systems, in our building design. Finally, we hoped to generate some general design parameters for low energy housing for the Northeast U.S. region.

B. The design strategy utilized to accomplish our first objective was two-fold: 1) minimize the heat losses for the building, so as to reduce heating requirements, and 2) attempt to supply the designed building's heating requirements by local, renewable energy sources (e.g. sun, wood, waste heat). In order to employ these strategies in a quantified manner, information on the specific environmental conditions in the State College area and the behavior of various building components and solar collectors within these local conditions was necessary. This information was partially gained through the use of a computer program, BEAP-3 (Building Environmental Analysis Program).[1] After obtaining the local weather data and some initial analysis of various building components, the computer program became non-operational for the remainder of our study (at the time of this writing, it is still non-operational).

As a result, the remaining analysis in the design process had to be accomplished, using hand calculations, which produced a much less accurate, and comprehensive analysis. Upon close examination of the initial analysis done by the computer, it appears that the program was not accounting for all the variables involved in heat flow calculations.

This section of the project will be developed in the following manner: 1) Initial Analysis - of environmental conditions and building components, 2) Synthesis and Design - of a shelter for thirty people, 3) Heat Flow Analysis - of the designed shelter, 4) Design of the space heating system(s), and 5) Conclusions.

II. INITIAL ANALYSIS

A. Environmental Conditions - In order to guide our design efforts, information on the specific weather data for our study area was necessary. The tabulated weather data we utilized for State College (Table 1) represents a 10-year average for local weather conditions. It was generated by the Monte Carlo Weather Simulator which utilized collected weather data from the University Park Weather Station. The average monthly wind speeds, temperatures (sun-rise and 3 P.M.), horizontal radiation, and heating degree and cooling degre days are directly from the simulator's output. The average night-time temperature is actually the monthly daily sun-rise temperature (from the simulator), and although it is somewhat lower than the actual average night-time temperatures, it will be used in the heat flow calculations. The average day-time temperatures on the table are actually averages of the average and 3 P.M. temperatures generated by the simulator. The average solar radiation on a 50° plane and a vertical surface facing true south, was calculated by the following formula:

$$\text{(Actual Horizontal Radiation)}\frac{\text{(Clear day radiation for 50° or 90°)}}{\text{(Clear day radiation for horizontal plane)}}$$

$$= \text{Actual Radiation at 50° or 90°}$$

The average soil temperatures at 3 feet were tabulated from soil temperatures measured by the Penn State Agronomy Research Station at Rock Springs. The sunrise to sunset hours were taken from "Low Temperature Engineering Applications of Solar Energy."[4]

Table 1

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	
AVE. WIND SPEED	8	9	10	9	9	6	6	6	7	8	10	11	MPH
AVE. TEMP.	29	29	37	48	60	69	72	70	63	53	41	31	°F
AVE. DAY-TIME TEMP.	34	38	47	57	71	75	80	77	74	62	47	37	°F (AVE. OF AVE + 3 PM TEMP.)
AVE. NIGHT-TIME TEMP.	23	22	30	37	49	65	69	66	52	43	30	24	°F (SUN-RISE TEMP)
AVE. HORIZ.[1] RADIATION	491	743	1090	1404	1685	1914	1888	1641	1323	946	557	436	BTU/DAY/ft^2
AVE. VERT.[1] RAD. (SOUTH)	894	906	872	632	472	440	528	722	1045	1164	986	916	BTU/DAY/ft^2
AVE. 60°[1] RAD. (SOUTH)	1140	1412	1439	1264	1112	1148	1208	1280	1482	1551	1234	1221	BTU/DAY/ft^2
AVE. SOIL TEMP. 36"	39.5	35.0	38.5	43.0	47.5	56.0	61.5	65.0	66.5	56.5	52.0	45.0	°F
HEATING DEGREE DAYS	1153	985	835	541	163	11	9	6	112	384	788	1069	
COOLING DEGREE DAYS	0	0	0	0	22	140	219	167	54	4	0	0	
SUNRISE TO SUNSET HOURS	9.50	10.52	11.77	13.12	14.23	14.83	14.57	13.61	12.33	11.03	9.82	9.18	HOURS

STATE COLLEGE WEATHER DATA

1) Accounting for cloud cover.

B. Building Component Analysis - Figures 1, 2, 3, and 4 represent tabulated heat flow data from analysis of various types of wall sections and window glass performed by the BEAP-5 program. For the wall sections we were primarily looking at three variables 1) orientation 2) thermal storage, and 3) thermal resistance (insulation). As can be seen in Figures 1 and 2 (and Appendix I), orientation does influence heat flow: north orientations losing the most heat in winter, southeast and west gaining the most in summer. Insulation is by far the most significant factor affecting heat flow. Heat loss graphs and data indicate that thermal storage (i.e. massive masonary walls with large thermal time lags) has no or negative impact on heat flow reduction. This is contrary to established concepts of thermal storage, indicating a fault in the program's ability to evaluate thermal time lag effects. On comparing the ratio of the components' U-value (thermal resistance) to the ratio of heat losses, the program appears to fluctuate heat loss in a linear pattern to the U-value, and therefore is not evaluating the thermal storage of the different types of wall assemblies. Wall sections with thermal time lags of from 2 to 17 hours were analyzed by the program as having no effect on heat loss, which cannot be true.

The variables involved with heat flow in glass are: 1) orientation 2) U-value, and 3) shading coefficient (transmission ability) of the glass. South facing glass surfaces show the least heat loss in winter; southwest and southeast show the highest heat gain in summer. The U-value has a significant effect on heat loss and gain: the lower the U-value, the lower the total energy flow. The shading coefficient on the other hand is sensitive to seasonal fluctuations. A high shading

coefficient (high transmission value) reduces heat loss in winter, but increases heat gain in summer. The reverse is true for a low shading coefficient. The best solution is to have a high shading coefficient and provide summer shading with the use of overhangs, shading devices, and vegetation. Tabulated data from the glass analysis appears in Tables 3 and 4 and Appendix I.

Figure 1

WALL	U VALUE	TIME LAG
1 - 16" COMMON BRICK W/ INSULATION	0.072	23
2 - 12" COMMON BRICK W/ INSULATION	0.077	17
3 - 4" COMMON, 4" FACE W/ INSULATION	0.085	8
4 - SIDING, FRAME WALL W/ INSULATION	0.080	1

WALL	U VALUE	TIME LAG
5 - 16" COMMON BRICK	0.247	13
6 - 12" COMMON BRICK	0.308	10
7 - 4" COMMON, 4" FACE	0.479	6
8 - SIDING, FRAME WALL	0.238	--

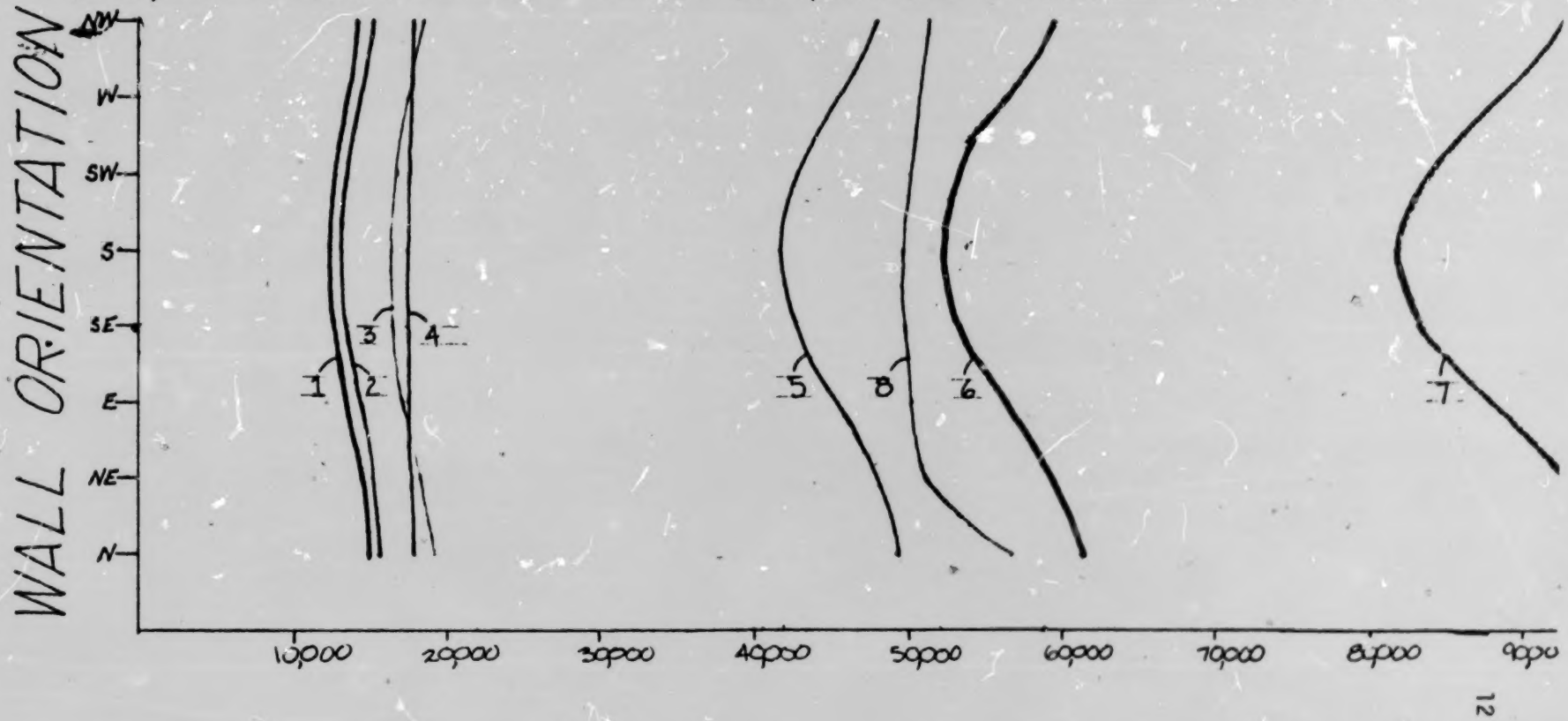


Figure 2

WALL	U VALUE	TIME LAG
1 - 16" COMMON BRICK W/INSULATION	0.072	23
2 - 12" COMMON BRICK W/INSULATION	0.077	17
3 - 4" COMMON, 4" FACE W/INSULATION	0.085	8
4 - SIDING, FRAME WALL W/INSULATION	0.080	1

WALL	U VALUE	TIME LAG
5 - 16" COMMON BRICK	0.247	13
6 - 12" COMMON BRICK	0.308	10
7 - 4" COMMON, 4" FACE	0.479	6
8 - SIDING, FRAME WALL	0.238	-

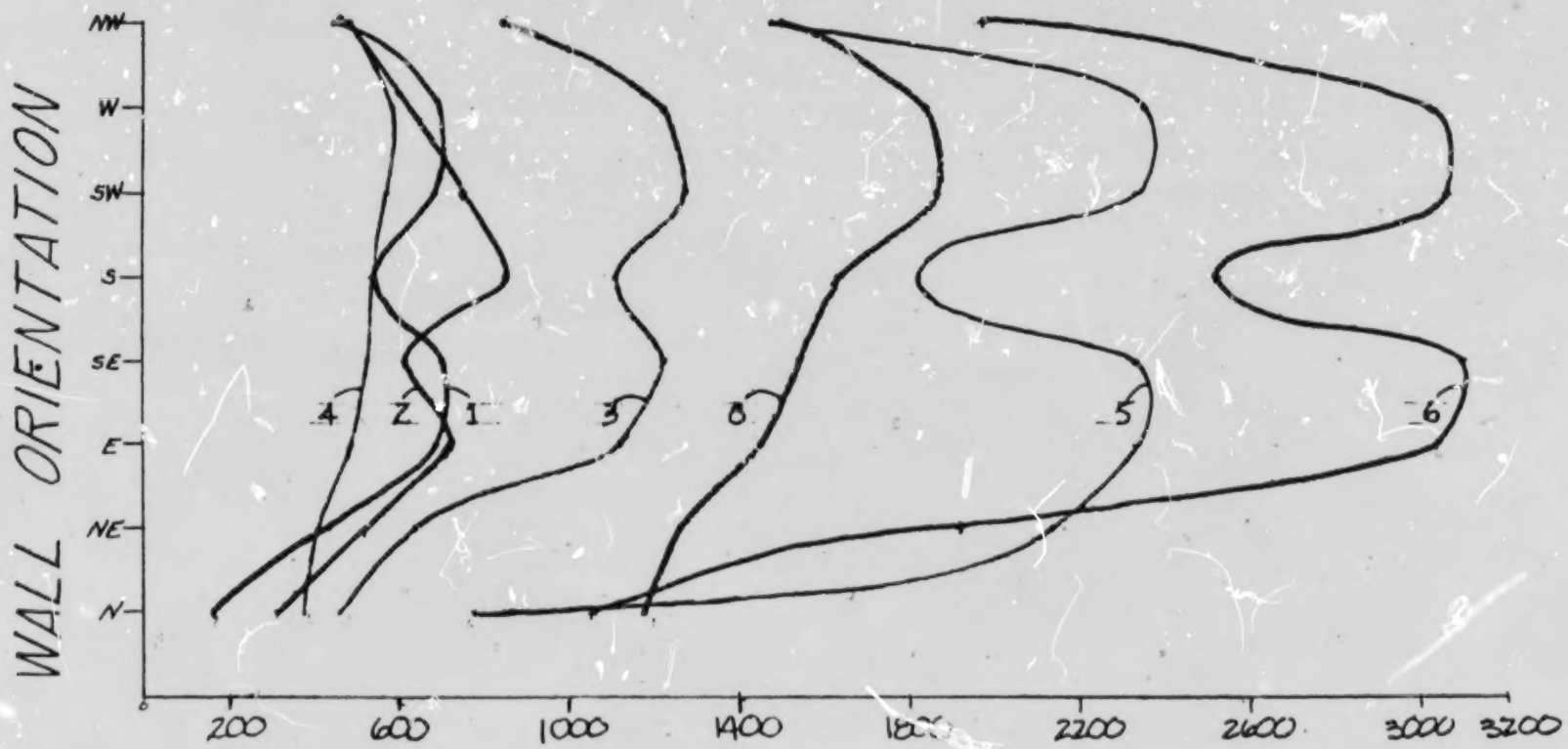


Figure 3

GLASS	U_{WINT}	SHADING COEF.
A=INSULATING	0.58	0.90
B=INSULATING	0.65	0.56
C=INSULATING	0.165	0.90
D=INSULATING	0.6	0.90

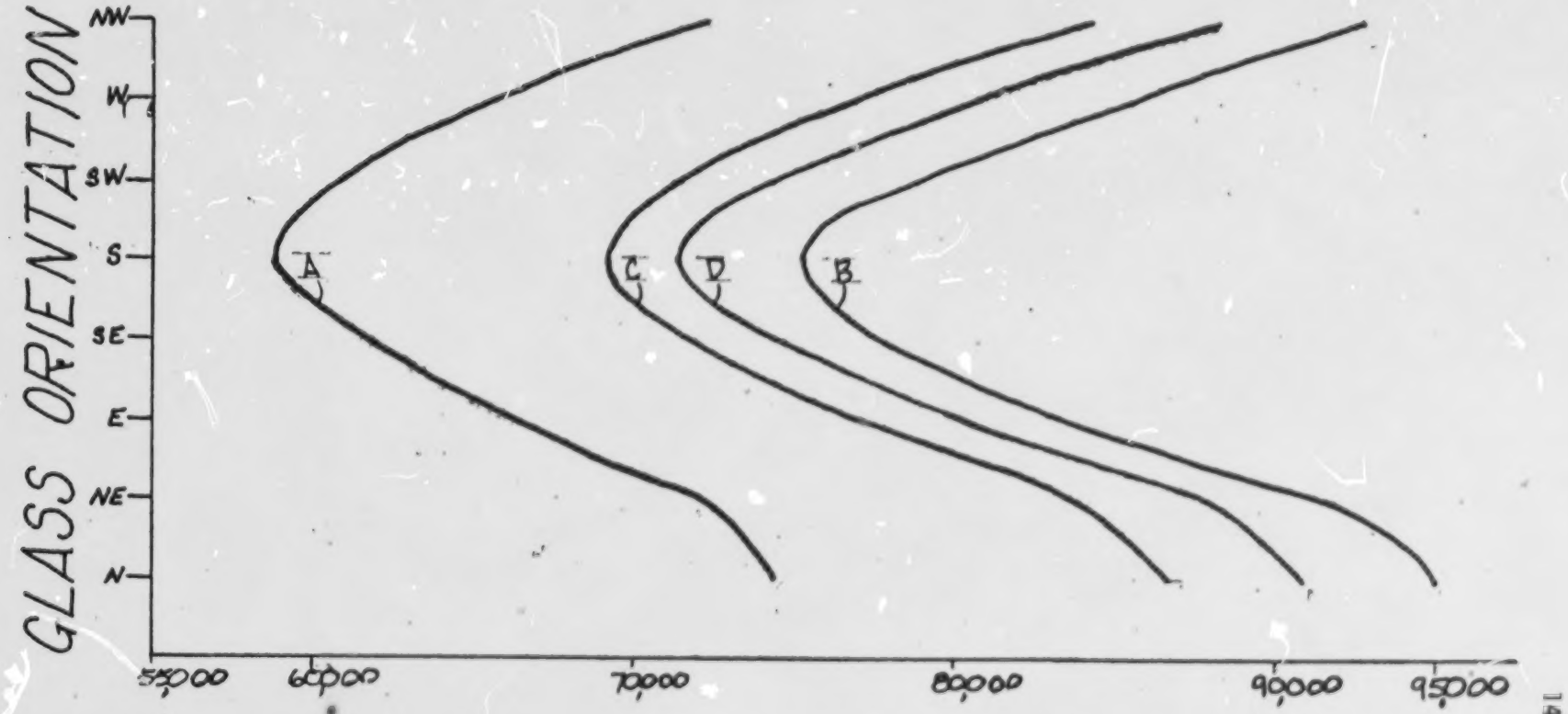
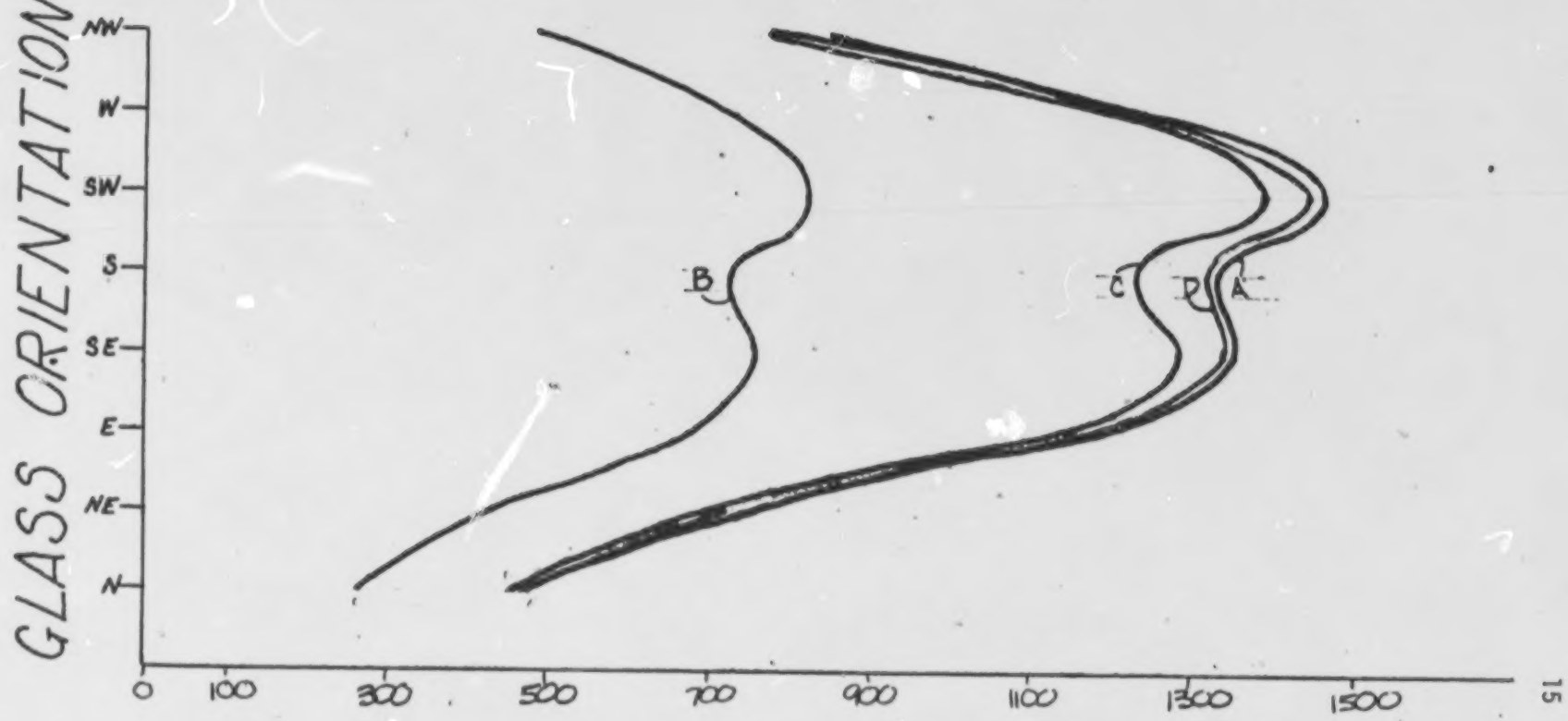


Figure 4

GLASS	U-VALUE	SHADING COEF.
A - INSULATING	0.50	0.90
B - INSULATING	0.65	0.[illegible]
C - INSULATING	0.65	0.90
D - INSULATING	0.69	0.90



III. BUILDING SYNTHESIS

As can be seen from Figure 5, the structure is semi-underground. The North section and roof, which are underground, serve a two-fold purpose. It reduces the air infiltration caused by the cold northern winds and it utilizes the ground water temperature to buffer the interior space from outside temperature fluctuations.

The building is designed to allow the deepest solar penetration into the spaces when natural solar heat is needed the most, i.e. during the under-heat period October-April. Orientation of the glass front is true south to maximize solar radiation gains. Special structural obstructions are provided to shade all glass areas during the overheat period, May-September. Additional vegetation will be provided to obstruct clear-sky radiation, that which is non-direct, from striking the glass surfaces by positioning planting areas within the structural configuration. Window areas which cannot be so shaded, will be provided with an adjustable wooden sun shield. Insulating glass with a high shading coefficient will be used on the southern walls. No glass will be used on the east or west sides. East and west windows might have reduced heat loss by increasing heat gains due to solar radiation, but the length of the building would have made the net solar gains very localized (at ends). To reduce summer heat gain, the glass will be shaded with overhangs, and to reduce winter heat loss, moveable insulation will be used to cover the glass at night. The east, south and west walls will be white stucco, insulation then block or stone. The stucco will reflect the solar radiation. The insulation will retard heat loss, and the block in the interior along with concrete floors will retain heat gained during the day through the large window areas.

Natural ventilation will be achieved by building orientation, and by the building's cross-sectional form. This form tends to produce a low pressure pocket at the peak and along the sloping roof, causing any air entering at the low and middle levels of the building to be drawn to roof top ventilators (Figure 9). When winds are calm, thus creating no pressure differential, mechanical assistance will be provided.

The building's general form is directly related to our climatic zone conditions (Northeastern U.S.). An elongated rectangle with 1:2:4 (height, width, length) proportions is a form which optimizes for minimized effects of wind and maximized receipts from solar radiation during the underheat period and the converse during the overheat period.[7] This was used as basic guide line, which, when incorporated with proper orientation, insulation, shading, and back filling on the north side gives a building "tuned" to our climate.

The structure of the complex would incorporate reinforced concrete, locally quarried limestone, and wood. This combination gives a structure of long-lasting and low maintenance characteristics; built from either renewable resources or materials which are labor rather than energy intensive.

Basically the building is well insulated to stop the brunt of heat loss and gain. The north wall, roof and some of the floors are backed with earth to reduce the impact of temperature fluctuations. Finally special care has been given to the glass areas to shade them in summer and retard heat flow on cold winter nights.

Figure 5

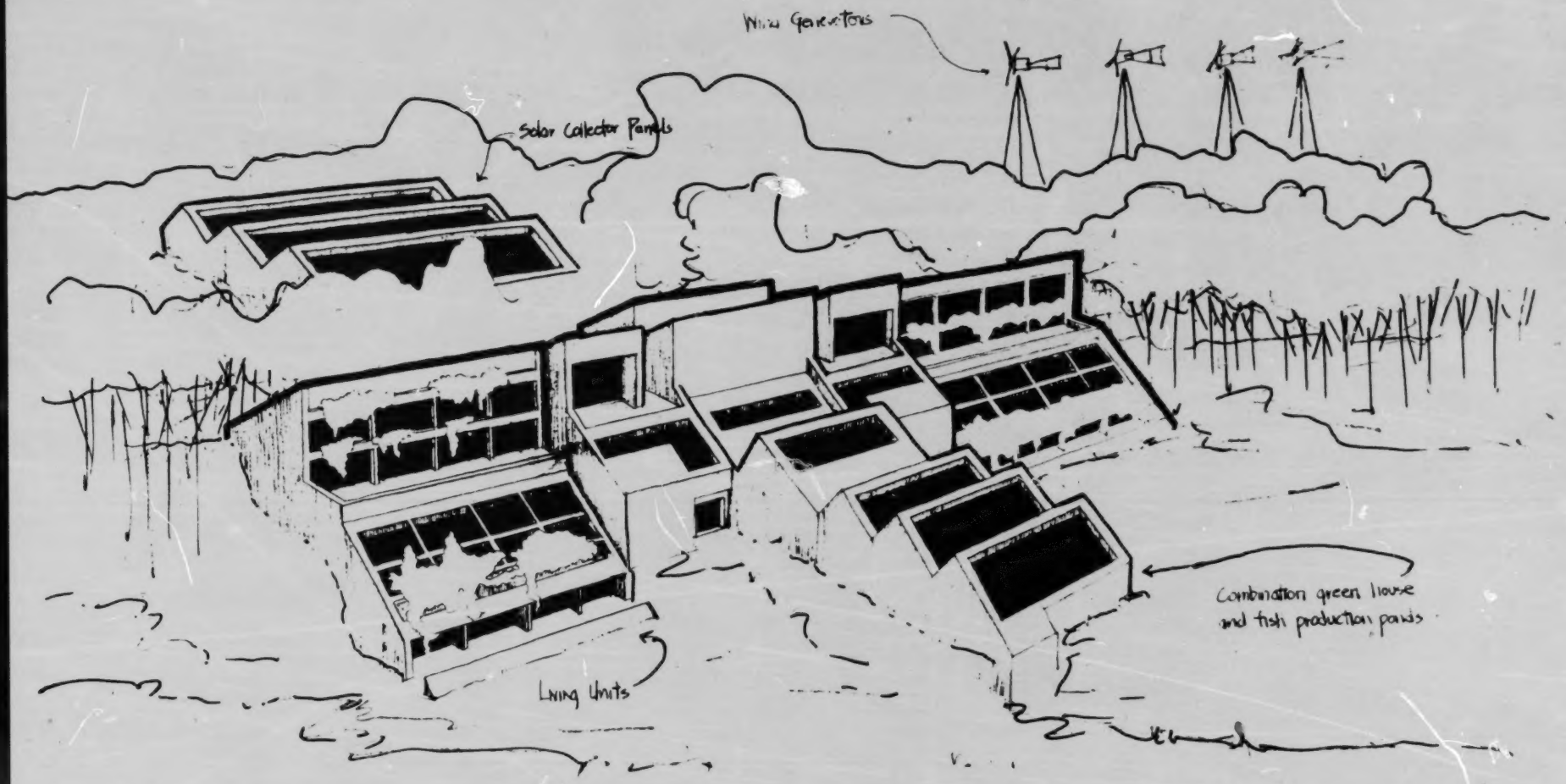
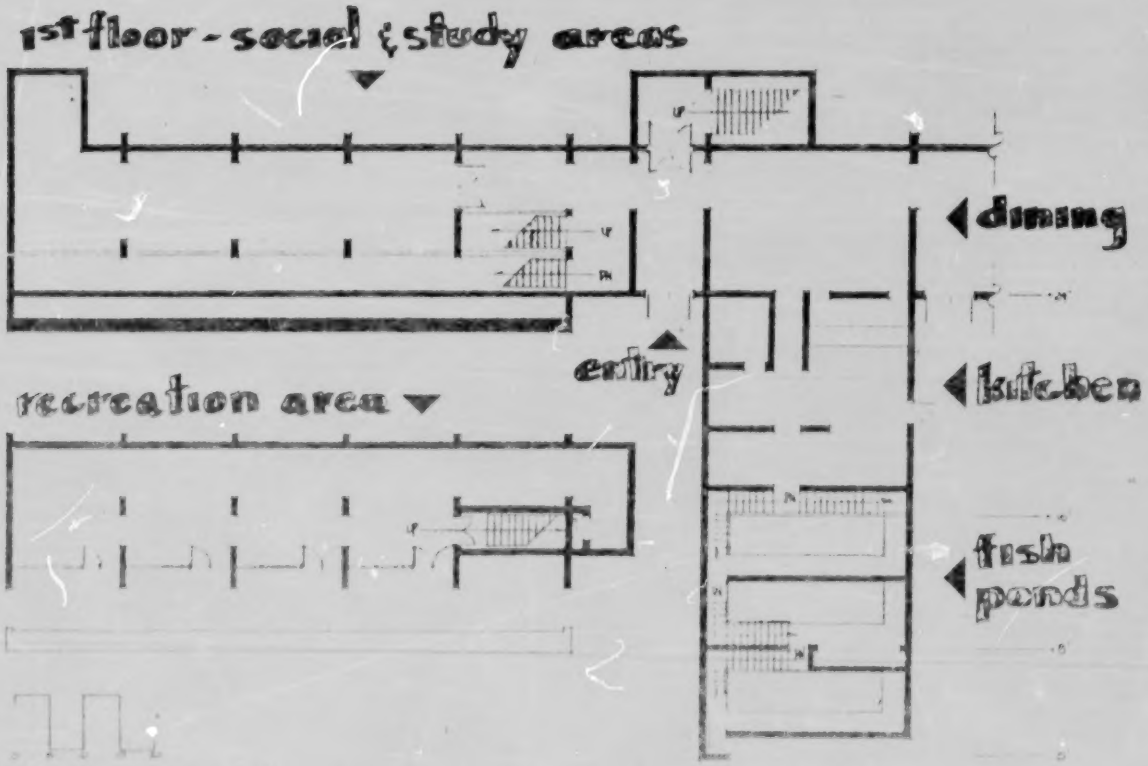
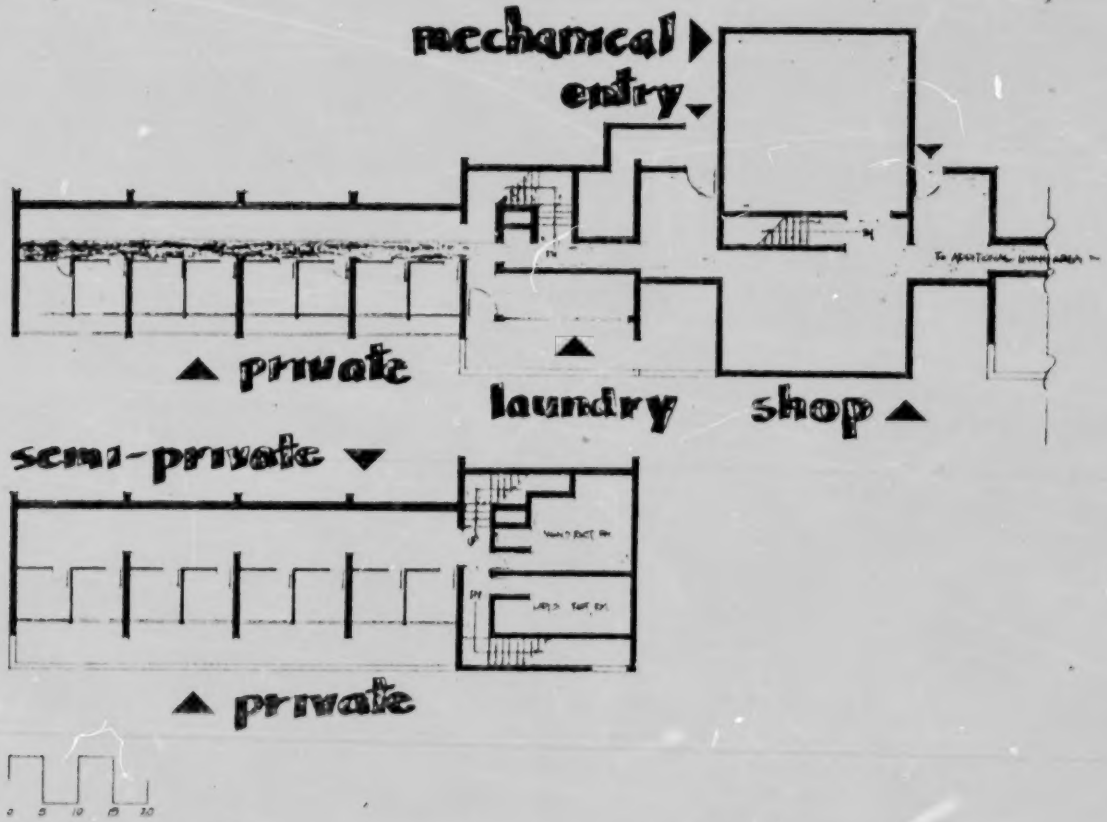

Wind Generators
Solar Collector Panels
Combination green house and fish production ponds
Living Units

Figure 6



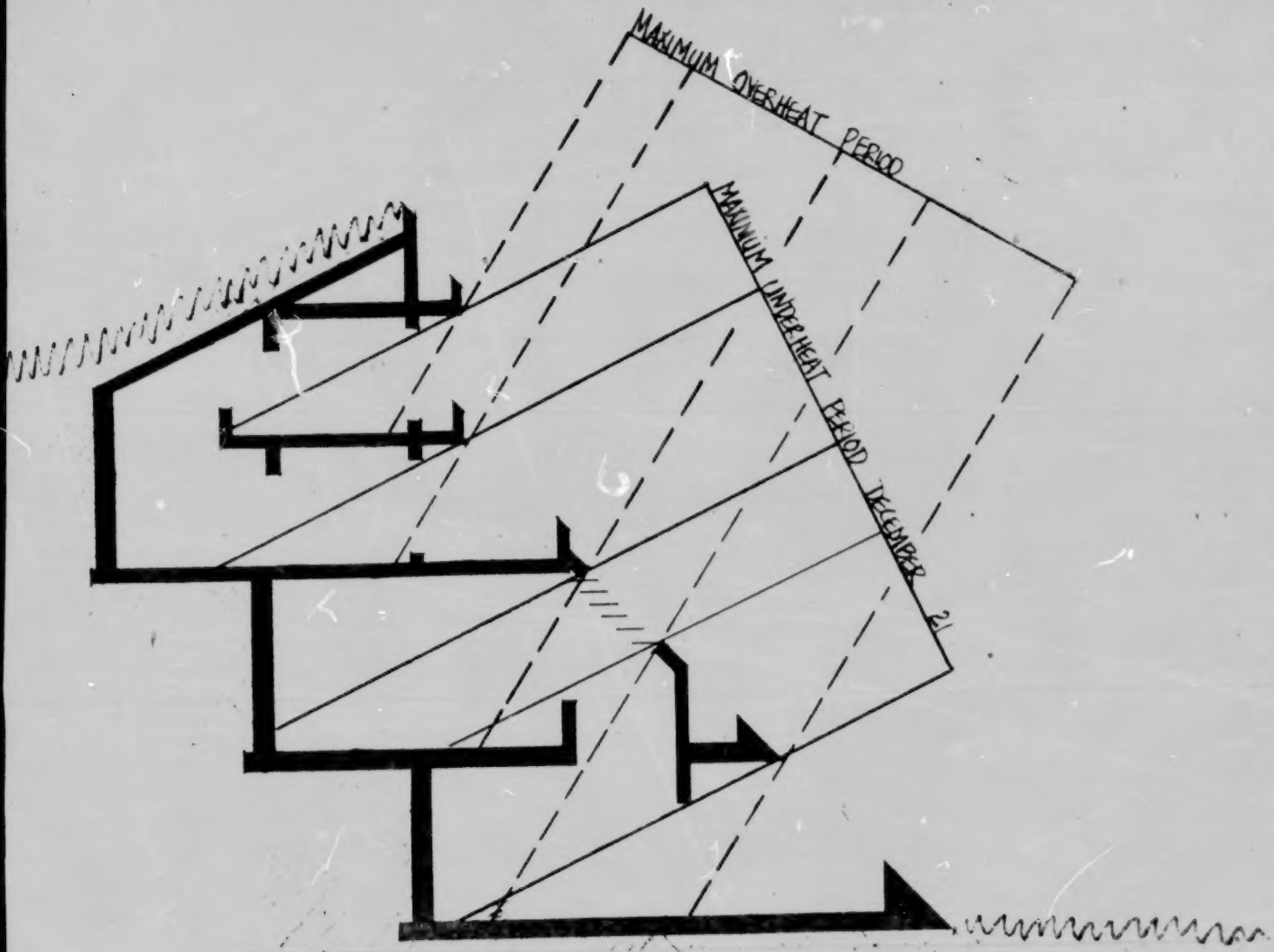
Ground & First floors - Support Areas

"Figure 7



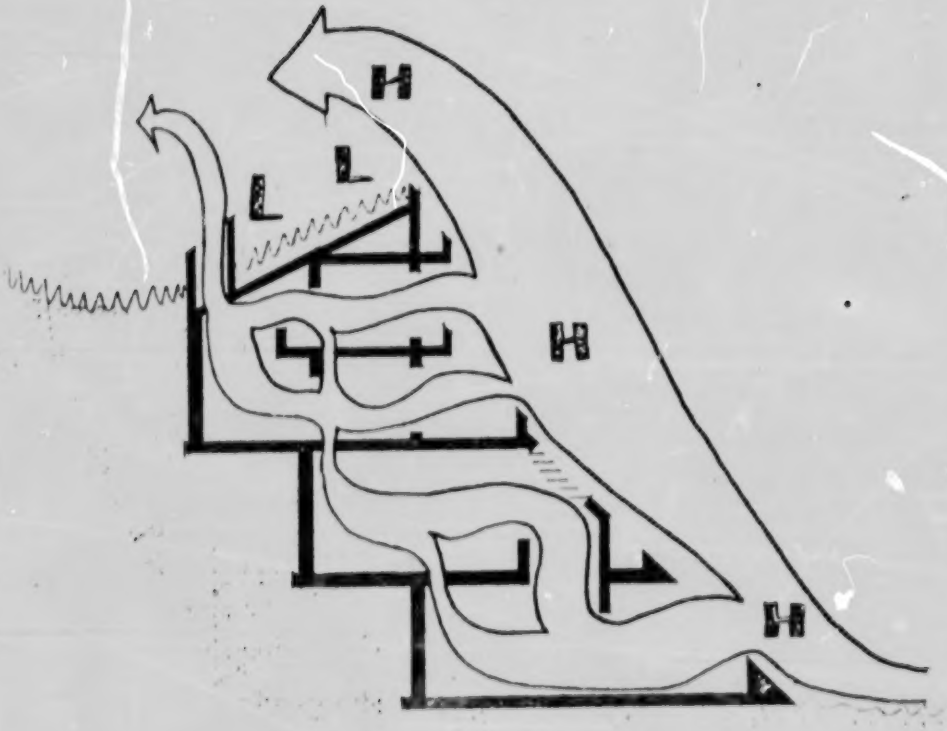
2nd & 3rd floors - Living Areas

Figure 8



Solar Penetration

Figure 9



Natural Ventilation

IV. BUILDING ANALYSIS - CALCULATIONS OF HEAT LOSS & HEAT GAIN

A. Walls, Floors and Glass

$HF = (A)(U)(\Delta T)(t)$ (negative values indicate heat gain, positive values indicate heat loss)

where HF = heat flow in BTU/hour
A = area
U = heat loss per degree farenheit/square foot ($BTU/Ft^2\text{-}°F$)
ΔT = indoor day bulb temperature minus outdoor temperature or assumed ground water temperature of 50°.
t = hours of heat loss

B. Infiltration

$HF = (p)(c)(V_c)(t)(A)$

where HF = heat flow in BTU
p = density of air
c = specific heat of air
V_c = air changes/hr. (assumed 1 air change/hr. w/15 mph wind)
A = adjustment factor for wind velocity

The static pressure varies with the square of the wind velocity. The ratio of the square of a known wind velocity to that of the square of 15 mph wind velocity gives the adjustment factor. I.e. $\frac{V_1^2}{V_o^2} = \frac{V_1^2}{15^2} = \frac{V_1^2}{225}$

Wind Velocity	$\frac{V_1^2}{V_o^2}$ = Adj. Factor
6	0.16
7	0.21
8	0.28
9	0.36
10	0.44
11	0.54
15	1.0

C. Lighting Load & Miscellaneous Heat Gain

Using 330 Kwh/mo. for the evening estimate, the total heat gain due to lighting is $(330 \frac{kwh}{mo})(\frac{3412\ BTU}{kwh})(\frac{THERM}{10^5 BTU}) = 8$ Therms/mo. for a module of 30 students.

D. Occupancy Heat Gain

Assuming an occupancy of 7.5 people during the day and 15 people during the night, the monthly heat gain from the people is:

Day - $(15\ people)(30\ days/mo)(400 \frac{BTUH}{Person})(\frac{Therm}{10^5 BTU}) = 26$ Therms gain.

Night - $(30\ people)(30\ days/mo)(400 \frac{BTUH}{Person})(\frac{Therm}{10^5\ BTU}) = 50$ Therms gain.

Note: 1 Therm = 100,000 BTU (10^5 BTU)

Table 2

Building Data Used in Heat Loss Calculations

		Area (ft^2)	U Value[b]	Materials
Walls Above[a] Grade		4840	0.07	Stucco - 2" Rigid Insulation - Block or Poured Concrete
Walls 0'-5' Below Grade		640	0.07	2" Rigid Insulation - Block or Poured Concrete + water proofing
5' Below Grade and Greater		4320	0.07	- 2" Rigid Insulation - Block or Poured Concrete
Roof		2720	0.05	2" Insulation - Concrete
Floors 0-5' Below Grade		320	0.09	2" Insulation - Concrete
Floors 5' Below and Greater		4320	0.09	2" Insulation - Concrete
Glass Vert.	W/O Insulating Curtain	1440	S.C.= 0.9 0.55	Insulating Glass
	With Insulating Curtain	1440	0.08	Insulating Glass + 1.5" Insulation and Air Space
Glass 50°	W/O Insulating Curtain	400	S.C.= 0.9 0.55	Insulating Glass
	With Insulating Curtain	400	0.08	Insulating Glass + 1.5" Insulation and Air Space

a) Window mullion area included in wall areas.

b) Similarly constructed building components will have slightly different U values depending on orientation, i.e. ceiling, wall, or floor.

E. Solar Radiation Heat Gain

Heat Gain (HG) = $AR\gamma$

where: A = area of glass

R = solar radiation/hour/ft^2

γ = % of glass not shaded

The percent of glass not shaded was found by using a Libbey-Owens-Ford, sun angle calculator. The useable solar radiation was found by examining the pattern of radiation and efficiency of its use on a clear day and then modifying this value for State College conditions:

1) The angle of incidence (on vertical and 50°) was determined for every hour between 8:00 A.M. and 4:00 P.M. solar time inclusive, by using the azimuth angles, altitudes, and tilt angles of the surfaces in question.
2) This incidence angle was used to determine the quantity of light transmitted through glass (at vertical and 50°) for each hour (as the angle of incidence increases, the quantity of radiation transmitted decreases).
3) The percent of total daily radiation falling on a surface occurring at each hour was calculated ($\frac{\text{Hourly Radiation}}{\text{Daily Radiation}}$) using the clear day condition as a model.
4) This percent was multiplied by the amount of light transmitted each hour, to give the percent of radiation transmitted through the glass every hour, assuming none of the glass is shaded.
5) This value was then multiplied by the percent of glass not shaded, to give the hourly heat gain of the glass on a clear day, as a percentage of the total daily radiation.

6) Then this hourly percent was multiplied by the actual average daily radiation (accounting for a cloud cover) for this sunrise to sunset hours for each month, thus determining the actual average solar radiation gain for every hour of the day for each month during the heating season.

7) Solar radiation conditions of 50% below average (representing complete cloud cover) and 50% above average conditions (representing relatively clear, but not cloudless days), with each occurring 15 days/month was assumed.

(Note: shadows caused by window mullions were considered negligible; only shadows caused by overhangs were considered.)

Table 3

Solar Radiation Transmitted Through Glass at 40° North Latitude

Solar Time		Angle of Incidence on Surface Facing		% Transmitted		Hourly Radiation / Daily Radiation	% of Daily Radiation Useable	
AM	PM	South Vertical	South 50°	Vert	50°	(% of daily rate)	Vert	50°
8	4	53°	60°	73	70	6	4.4	4.2
9	3	47°	49°	75	73	10	7.5	7.3
10	2	36°	34°	76	76	12	9.1	9.1
11	1	28°	20°	78	78	14	10.9	10.9
12		27°	14°	78	79	14	10.9	11.1
			% Useable Clear Day Radiation				74.7	74.1

DECEMBER

Solar Time		Angle of Incidence on Surface Facing		% Transmitted		Hourly Radiation / Daily Radiation	% of Daily Radiation Useable	
AM	PM	South Vertical	South 50°	Vert	50°	(% of daily rate)	Vert	50°
8	4	71°	71°	60	60	6	3.6	3.6
9	3	63°	57°	70	73	10	6.3	6.6
10	2	57°	42°	73	75	12	8.8	9.0
11	1	53°	26°	73	78	14	10.2	10.9
12		50°	11°	75	79	14	10.5	11.1
			% Useable Clear Day Radiation				68.3	71.3

SEPTEMBER 21 & MARCH 21

Table 3 (continued)

Solar Radiation Transmitted Through Glass at 40° North Latitude

Solar Time		Angle of Incidence on Surface Facing		% Transmitted		Hourly Radiation / Daily Radiation	% of Daily Radiation Useable	
AM	PM	South Vertical	South 50°	Vert	50°	(% of daily rate)	Vert	50°
8	4	64°	64°	70	70	6	4.2	4.2
9	3	56°	50°	73	73	10	7.3	7.3
10	2	46°	36°	75	76	12	9.0	9.1
11	1	41°	18°	75	78	14	10.5	10.9
12		40°	0°	75	80	14	10.5	11.2
			% Useable Clear Day Radiation				72.5	74.2

OCTOBER 21 & FEBRUARY 21

Solar Time		Angle of Incidence on Surface Facing		% Transmitted		Hourly Radiation / Daily Radiation	% of Daily Radiation Useable	
AM	PM	South Vertical	South 50°	Vert	50°	(% of daily rate)	Vert	50°
8	4	56°	61°	73	70	6	4.4	4.2
9	3	46°	41°	75	75	10	7.5	7.5
10	2	38°	34°	76	76	12	9.1	9.1
11	1	33°	20°	77	78	14	10.8	10.9
12		29°	11°	78	79	14	10.9	11.1
			% Useable Clear Day Radiation				74.5	74.5

NOVEMBER 21 & JANUARY 21

Table 3 (continued)

Solar Radiation Transmitted Through Glass at 40° North Latitude

Solar Time		Angle of Incidence on Surface Facing		% Transmitted		Hourly Radiation / Daily Radiation	% of Daily Radiation Useable	
AM	PM	South Vertical	South 50°	Vert	50°	(% of daily rate)	Vert	50°
8	4	81°	80°	37	37	6	2.2	2.2
9	3	73°	67°	60	57	10	6.0	5.7
10	2	66°	52°	57	73	12	6.8	8.8
11	1	63°	34°	70	76	14	9.8	10.6
12		62°	22°	70	78	14	10.6	10.9
			% Useable Clear Day Radiation				60.2	65.5

APRIL 21

Solar Time		Angle of Incidence on Surface Facing		% Transmitted		Hourly Radiation / Daily Radiation	% of Daily Radiation Useable	
AM	PM	South Vertical	South 50°	Vert	50°	(% of daily rate)	Vert	50°
8	4	88°	87°	40	40	6	2.4	2.4
9	3	81°	76°	37	45	10	3.7	4.5
10	2	77°	64°	45	70	12	5.4	8.4
11	1	72°	44°	57	75	14	8.0	10.5
12		70°	30°	60	78	14	8.4	10.9
			% Useable Clear Day Radiation				47.4	62.5

MAY 21

F. Total Day Time Heat Loss - calculated on an hourly basis for each month.[a]

1. Hourly Heat Loss for walls 5' or greater below grade = 2725 BTU/hr

2. Hourly heat loss for floors = = 3500 BTU/hr / 6225 BTU/hr

(These two are constant throughout year, because constant temperatures were assumed for below 5' from grade)

3. Walls and floor 0-5 below grade

(22.4 + 68 + 14.4) (68 - monthly temp. @ 3' below surface) = heat loss

Areas x U of wall and floors @ 0-5' below grade (in BTU/°F/hr)

(assumes that ground temperature at 0-5' below grade is equal to monthly soil temp. @ 3')

4. Above grade - walls, roof, glass

(169.4 + 396 + 110) (68 - outdoor dry bulb temp.) = heat loss

Areas x U-values of wall roof & glass (in BTU/°F/hr)

5. Hourly solar gain - Hourly values (from tables -) of percent of daily radiation transmitted through glass/hour (clear day) x Daily Radiation actually occurring (accounting for cloud cover) x percent of glass not shaded = solar gain

(Assumes that below (50%) average conditions will occur 15 days of month and above average conditions (50%) occur 15 days of the month.)

6. Total Daily Heat Loss

Heat loss/day = $\sum_{\text{sunrise hrs}}^{\text{sunset hrs}}$ (HL below grade + HL perimeter + HL above grade + HL infiltration + HG internal[b] + HG solar)

7. Monthly Heat Loss = daily heat loss x number of days/month

Tables 3X-7 are the tabulated daytime monthly heat losses for the designed building.

a) This was done to more accurately determine the affects of solar heat gain in offsetting heat loss.

b) Includes gain from occupancy - but assumes no gain from lighting during day.

Table 4-A

					HEAT LOSSES - BTU/HR			HEAT GAINS - BTU/HR				
SOLAR TIME	IDBT[a]	ODBT[a]	ΔT[c]	AU[d]	HEAT LOSS ABOVE GRADE	0'-5' BELOW GRADE	BELOW 5'	SOLAR VERT	SOLAR 50°	INTERNAL	INFILTRATION	NET TOTALS (THERMS/HR)
7	68	52	16	675.4	10810	157	6225	--	--	3600	1888	.154
8	↓	54	14	↓	9460	↓	↓	13550	5340	↓	1650	-.050
9		56	12		8100			23700	9780		1420	-.212
10		59	9		6080			33100	13340		1060	-.365
11		62	6		4050			38400	16150		710	-.481
12		65	3		2025			39500	16450		355	-.508
1		68	0		--			38400	16150		--	-.518
2		71	-3		-2025			33160	13340		-355	-.542
3		74	-6		-4050			23700	9780		-710	-.348
4		73	-5		-3380			13550	5340		-590	-.201
5		72	-4		-2700			--	--		-470	-.388
6		71	-3		-2025			--	--		-355	.004
	↓			↓		↓	↓			↓		

Net Heat Loss - .158 Therms/day
(half building)

9.5 Therms/month
(total building)

SEPTEMBER

43

a) Indoor dry bulb temperature
b) Outdoor dry bulb temperature
c) Temperature difference between indoor and outdoor temperatures.
d) Area of glass x U of glass.

Table 4-B

					HEAT LOSSES - BTU/HR			HEAT GAINS - BTU/HR				
SOLAR TIME	IDBT[a]	ODBT[a]	ΔT[c]	AU[d]	HEAT LOSS ABOVE GRADE	0'-5' BELOW GRADE	BELOW 5'	SOLAR VERT	SOLAR 50°	INTERNAL	INFILTRATION	NET TOTALS (THERMS/HR)
7	68	43	25	675.4	16885	1200	6225	--	--	3600	3925	.246
8		45	23		15535			23600	8700		3610	-.093
9		47	21		14183			41000	15200		3300	-.349
10		49	19		12830			50500	18900		2980	-.498
11		51	17		11480			59000	22700		2670	-.637
12		54	14		9450			59000	23300		2200	-.668
1		57	11		7430			59000	22700		1730	-.687
2		60	8		5400			50500	18900		1260	-.589
3		63	5		3380			41000	15200		785	-.482
4		62	6		4050			23600	8700		940	-.235
5		61	7		4730			--	--		1100	.096

Net Heat Loss - .343 Therms/day
(half building)

21.2 Therms/month
(total building)

OCTOBER

a) Indoor dry bulb temperature
b) Outdoor dry bulb temperature
c) Temperature difference between indoor and outdoor temperatures.
d) Area of glass x U of glass.

Table 4-C

					HEAT LOSSES - BTU/HR			HEAT GAINS - BTU/HR				
SOLAR TIME	IDBT[a]	ODBT[a]	ΔT[c]	AU[d]	HEAT LOSS ABOVE GRADE	0'-5' BELOW GRADE	BELOW 5'	SOLAR VERT	SOLAR 50°	INTERNAL	INFILTRATION	NET TOTALS (THERMS/HR)
8	68	30	38	675.4	25670	1680	6225	25900	8600	3600	9350	.048
9		33	35		23640			44200	15400		8610	-.230
10		36	32		21610			53600	18600		7870	-.384
11		39	29		19590			63600	22300		7130	-.412
12		42	26		17560			64200	22700		6400	-.586
1		46	22		14860			63600	23300		5410	-.623
2		49	19		12830			53600	18600		4670	-.504
3		52	16		10810			44200	15400		3940	-.405
4		51	17		11480			25900	8600		4182	-.145
5		50	18		12160			--	--		4430	.209
	↓			↓		↓	↓			↓		

Net Heat Loss - .257 Therms/day
(half building)

15.4 Therms/month
(total building)

NOVEMBER

33

a) Indoor dry bulb temperature
b) Outdoor dry bulb temperature
c) Temperature difference between indoor and outdoor temperatures.
d) Area of glass x U of glass.

47

48

Table 4-D

SOLAR TIME	IDBT[a]	ODBT[a]	ΔT[c]	AU[d]	HEAT LOSSES - BTU/HR			HEAT GAINS - BTU/HR			INFILTRATION	NET TOTALS (THERMS/HR)
					HEAT LOSS ABOVE GRADE	0'-5' BELOW GRADE	BELOW 5'	SOLAR VERT	SOLAR 50°	INTERNAL		
8	68	24	44	675.4	29720	2410	6225	2900	10300	3600	13300	.084
9		26	42		28370			49500	17800		12700	-.176
10		28	40		27020			60000	22200		12100	-.380
11		30	38		25670			71900	26600		11475	-.563
12		32	36		24310			71900	27100		10870	-.587
1		34	34		22960			71900	26600		10270	-.602
2		36	32		21610			49500	22200		9970	-.351
3		38	30		20262			29000	17800		9060	-.124
4		37	29		19590			29000	17800		8760	-.134

Net Heat Loss - .084 Therms/day
(half building)

5.1 Therms/month
(total building)

DECEMBER

a) Indoor dry bulb temperature
b) Outdoor dry bulb temperature
c) Temperature difference between indoor and outdoor temperatures.
d) Area of glass x U of glass.

Table 4-E

					HEAT LOSSES - BTU/HR			HEAT GAINS - BTU/HR				
SOLAR TIME	IDBT[a]	ODBT[a]	ΔT[c]	AU[d]	HEAT LOSS ABOVE GRADE	0'-5' BELOW GRADE	BELOW 5'	SOLAR VERT	SOLAR 50°	INTERNAL	INFILTRATION	NET TOTALS (THERMS/HR)
8	68	23	45	675.4	30400	2990	6225	23500	6950	3600	7060	.126
9		24	44		29720			40100	12500		6910	.126
10		25	43		29040			48600	15100		6750	.126
11		27	41		27690			57700	18000		6440	.126
12		29	39		26340			58200	18400		6120	.126
1		31	37		24990			57700	18000		5810	.126
2		33	35		23640			48600	15100		5500	.126
3		35	33		22290			40100	12500		5180	.126
4		34	34		22290			23500	6950		5340	.126

Net Heat Loss - .160 Therms/day
(half building)

10 Therms/month
(total building)

JANUARY

35

a) Indoor dry bulb temperature
b) Outdoor dry bulb temperature
c) Temperature difference between indoor and outdoor temperatures.
d) Area of glass x U of glass.

52

Table 4-F

SOLAR TIME	IDBT[a]	ODBT[a]	ΔT[c]	AU[d]	HEAT LOSSES - BTU/HR: HEAT LOSS ABOVE GRADE	HEAT LOSSES - BTU/HR: 0'-5' BELOW GRADE	HEAT LOSSES - BTU/HR: BELOW 5'	HEAT GAINS - BTU/HR: SOLAR VERT	HEAT GAINS - BTU/HR: SOLAR 50°	HEAT GAINS - BTU/HR: INTERNAL	INFILTRATION	NET TOTALS (THERMS/HR)
7	68	22	46	675.4	31070	3460	6225	--	--	3600	9300	.454
8		23	45		30400			18400	4900		9090	.222
9		24	44		29720			31900	8900		8890	.039
10		26	42		28370			39300	12100		8490	-.084
11		28	40		27020			45900	14700		8080	-.194
12		30	38		25670			45900	15000		7680	-.214
1		32	36		24310			45900	14700		7270	-.229
2		34	34		22960			39300	12100		6870	-.155
3		36	32		21610			31900	8900		6460	-.066
4		35	33		22290			18400	4900		6670	.117

Net Heat Loss - .850 Therms/day
(half building)

47.6 Therms/month
(total building)

FEBRUARY

36

a) Indoor dry bulb temperature
b) Outdoor dry bulb temperature
c) Temperature difference between indoor and outdoor temperatures.
d) Area of glass x U of glass.

Table 4-G

SOLAR TIME	IDBT[a]	ODBT[a]	ΔT[c]	AU[d]	HEAT LOSSES - BTU/HR: HEAT LOSS ABOVE GRADE	HEAT LOSSES - BTU/HR: 0'-5' BELOW GRADE	HEAT LOSSES - BTU/HR: BELOW 5'	HEAT GAINS - BTU/HR: SOLAR VERT	HEAT GAINS - BTU/HR: SOLAR 50°	HEAT GAINS - BTU/HR: INTERNAL	INFILTRATION	NET TOTALS (THERMS/HR)
7	68	30	38	675.4	25670	3090	6225	--	--	3600	9350	.407
8		33	35		23640			11300	5200		9100	.220
9		36	32		21610			19800	9500		8860	-.069
10		39	29		19590			27600	13000		8630	-.067
11		42	26		17560			32100	15700		7870	-.167
12		45	21		14180			33000	16000		7380	-.217
1		49	19		12830			32100	15700		6890	-.224
2		53	15		10130			27600	13000		6400	-.184
3		57	11		7430			19800	9500		5900	-.160
4		55	13		8780			11300	5200		6150	.004
5		53	15		10130			--	--		6400	.222
	▽			▽		▽	▽			▽		

Net Heat Loss - .853 Therms/day
(half building)

53 Therms/month
(total building)

MARCH

37

a) Indoor dry bulb temperature
b) Outdoor dry bulb temperature
c) Temperature difference between indoor and outdoor temperatures.
d) Area of glass x U of glass.

Table 4-H

SOLAR TIME	IDBT[a]	ODBT[a]	ΔT[c]	AU[d]	HEAT LOSSES - BTU/HR: HEAT LOSS ABOVE GRADE	HEAT LOSSES - BTU/HR: 0'-5' BELOW GRADE	HEAT LOSSES - BTU/HR: BELOW 5'	HEAT GAINS - BTU/HR: SOLAR VERT	HEAT GAINS - BTU/HR: SOLAR 50°	HEAT GAINS - BTU/HR: INTERNAL	INFILTRATION	NET TOTALS (THERMS/HR)
6	68	37	31	675.4	20940	2620	6225	--	--	3600	6260	.325
7		40	28		18900			--	--		5860	.300
8		43	25		16885			3300	1800		5450	.224
9		46	22		14860			9000	4800		5050	.114
10		49	19		12830			10200	7300		4650	.050
11		52	16		10810			14700	8800		4240	-.003
12		56	12		8100			15900	9100		3640	-.060
1		60	8		5400			14700	8800		3030	-.100
2		63	5		3380			10200	7300		2425	-.060
3		66	2		1350			9000	4800		1820	-.050
4		65	3		2030			3300	1800		2020	.040
5		64	4		2700			--	--		2220	.100
6		63	5		3380			--	--		2425	.110

Net Heat Loss - 1.22 Therms/day
(half building)

73.0 Therms/month
(total building)

APRIL

a) Indoor dry bulb temperature
b) Outdoor dry bulb temperature
c) Temperature difference between indoor and outdoor temperatures.
d) Area of glass x U of glass.

G. Night time heat loss = Areas x U values x ΔT x total night hours/ month + Infiltration Loss - Internal Gains (Night time internal gains assumes full occupancy (30 people) and 330 Kwhrs electrical gain = 1.9 Therms/night x nights/month.

Sample Monthly Night Time Heat Loss (January)

	A x U BTU/°F-HR	ΔT °F	HOURS DARK/ MONTH	HEAT LOSS (THERMS)
WALLS ABOVE GRADE	4840 x .07= 338.8	68-23= 45	449	68
WALLS 0'-5' BELOW GRADE	640 x .07= 44.8	68-39.5= 28.5	449	6
5' BELOW GRADE & GREATER	4320 x .07= 302.4	68-50= 18	449	24
GLASS VERTICAL	1440 x .08= 115.2	68-23= 45	449	24
GLASS 50°	400 x .08= 32	68-23= 45	449	6
ROOF	2720 x .05= 136	68-39.5= 28.5	449	18
FLOOR 0'-5' FROM GRADE	320 x .09= 28.8	68-39.5= 28.5	449	4
FLOOR 5' AND GREATER	4320 x .09= 388.8	68-50= 18	449	32
TOTAL				182 THERMS

Table 5

Table 6

HEAT LOSS - INFILTRATION (Nightime)

	Q $\frac{\text{Therms}}{^{\circ}\text{F-Hr.}}$	Adj. Factor for Wind	ΔT (Night)	Hrs/month of night	Heat Loss (Therms/mo)
Sept.	.0112	0.21	16	350	14
Oct.		0.28	25	402	32
Nov.		0.44	38	425	80
Dec.		0.54	44	459	122
Jan.		0.28	45	449	64
Feb.		0.36	46	377	70
Mar.		0.44	38	379	70
Apr.		0.36	31	326	42
May		0.36	19	303	22

Table 7

Total Building Heat Loss

	Building Heat Loss	Infiltration Heat Loss	Internal Heat Gain	Total Building Heat Loss	
Sept.	--	--	--	10	Day
	70	14	-58	26	Night
Oct.	--	--	--	21	Day
	118	32	-58	92	Night
Nov.	--	--	--	15	Day
	148	80	-58	170	Night
Dec.	--	--	--	5	Day
	176	122	-58	240	Night
Jan.	--	--	--	10	Day
	182	64	-58	188	Night
Feb.	--	--	--	48	Day
	156	70	-58	168	Night
Mar.	--	--	--	53	Day
	140	70	-58	152	Night
Apr.	--	--	--	73	Day
	112	42	-58	96	Night
May	--	--	--	35	Day
	78	22	-58	42	Night

Total 1444 Therms

Table 8

Tabulated Heat Loss for Building With and Without Insulating Curtains Covering the Windows During the Night Hours

	Without Insulation	With Insulation	Generator	Total Heat Loss Without Insulation	Total Heat Loss With Insulation
Sept.	60	36	7	67	42
Oct.	152	113	7	159	120
Nov.	255	185	9	264	194
Dec.	332	245	11	343	256
Jan.	285	198	11	296	209
Feb.	291	216	11	302	227
Mar.	268	205	11	279	216
Apr.	212	169	10	222	179
May	102	77	9	111	86
Total	1957 Therms	1444 Therms	86 Therms	2043 Therms	1530 Therms

V. SPACE HEATING SYSTEM

The space heating system (Fig.) is comprised of four major components: 1) solar flat plate collectors, 2) storage tank containing a mixture of ethylene-glycol and water, 3) distribution system, 4) auxillary fuel supply. A solar dependency of 50% (of total heating requirements) was the design goal, because this is recommended as the most feasible in areas of high cloud cover. Performance and sizing of the collectors was determined by information from Tables A-B and Fig. 4.

Temperature sensors are located in the collector and storage tank. When the collector temperature is higher than the tank temperature the pump will circulate the water mixture through the collector where it is heated, then carried to the tank where the heat is exchanged and stored. If the tank temperature drops below one acceptable level (100°F) another sensor in the tank will turn on an auxillary fuel source (wood, gas, oil, coal). A second heat exchanger in the tank transfers the heat into a hot-water heating loop and fin tube, baseboard, radiators. Circulation in the heating loop is controlled by a thermostat operated pump. A similar loop is connected to the methane generator (see Section III) to provide heat if necessary. Check valves limit flows to one direction.

Energy requirements using different fuel sources are tabulated in Table 9.

Figure 10

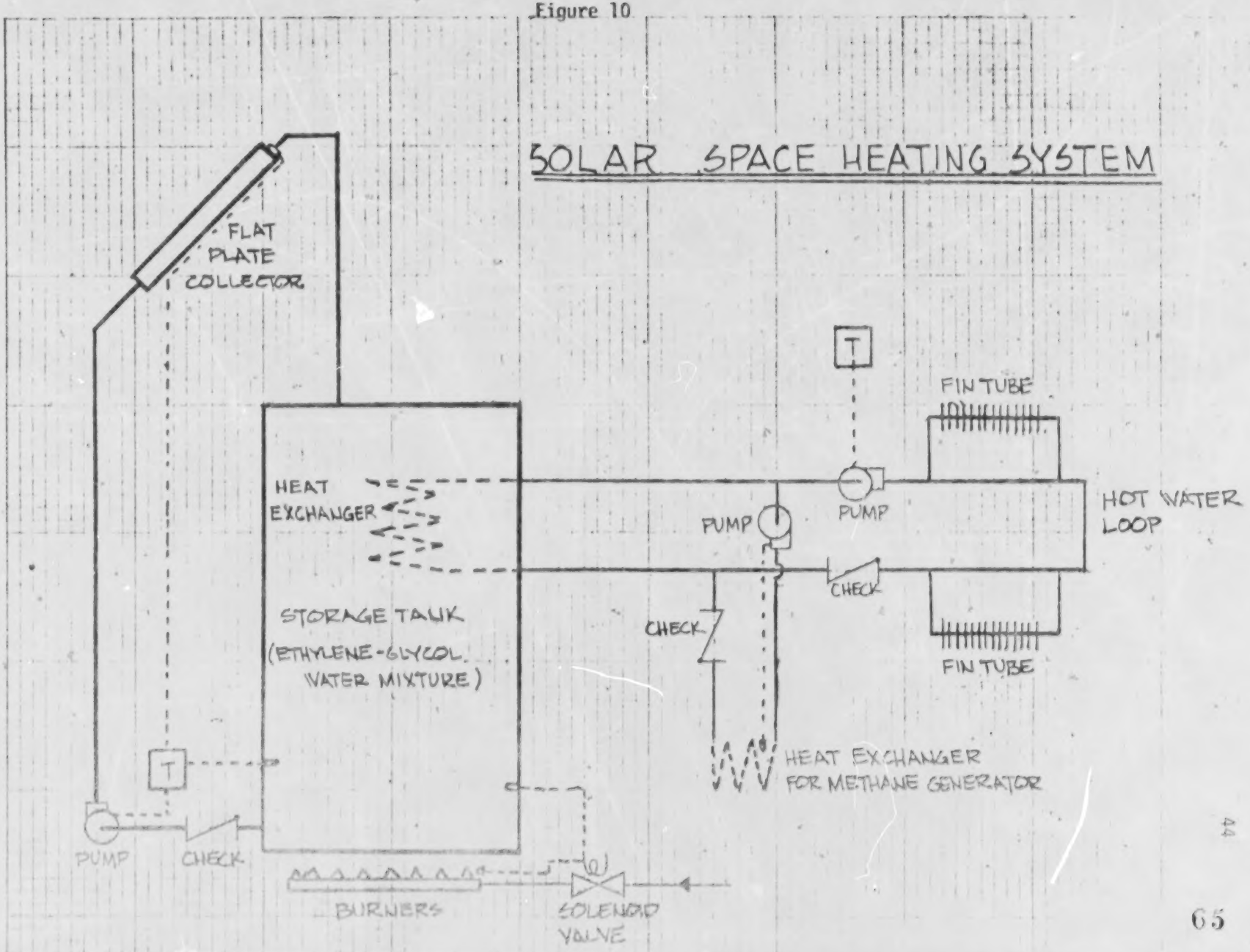
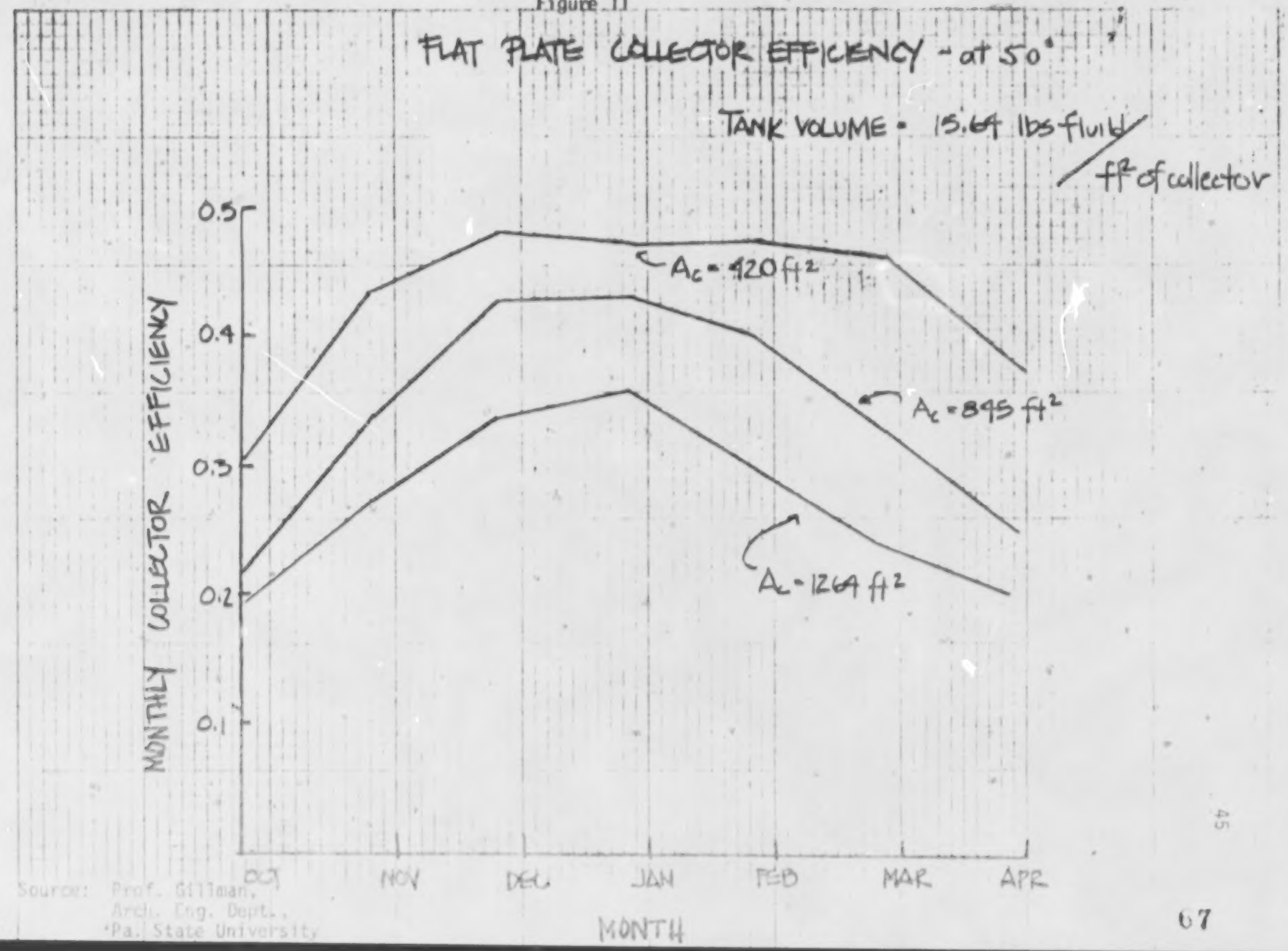

SOLAR SPACE HEATING SYSTEM
FLAT PLATE COLLECTOR
HEAT EXCHANGER
STORAGE TANK
(ETHYLENE-GLYCOL WATER MIXTURE)
T
PUMP
CHECK
BURNERS
SOLENOID VALVE
CHECK
PUMP
PUMP
CHECK
FIN TUBE
FIN TUBE
HOT WATER LOOP
HEAT EXCHANGER FOR METHANE GENERATOR

Figure 11



Source: Prof. Gillman,
Arch. Eng. Dept.,
Pa. State University

Table 9

	Total Demand W/O Insulation[a]	Total Demand W/Insulation[a]	Solar Rad. at 50° Therms/mo-Ft^2	Solar Radiation Striking Collector Surface Area = 845 Ft^2	Collector Efficiency	Useable Heat	Additional Heat Req'd W/O Insul.	Additional Heat Req'd W/Insul.
Sept.	67	42	0.44	372	0.16	60	7	--
Oct.	159	120	0.48	406	0.22	89	70	31
Nov.	264	194	0.37	313	0.34	106	158	88
Dec.	343	256	0.38	321	0.43	138	205	118
Jan.	296	209	0.35	296	0.44	130	166	79
Feb.	302	227	0.40	338	0.41	139	163	88
Mar.	279	216	0.45	380	0.34	129	150	87
Apr.	222	179	0.30	254	0.21	53	169	126
May	111	86	0.34	287	0.17	49	62	37
	2043	1530					1150	654

Bldg. W/O Insulation on glass	$\frac{2043-1150}{2043}$ = 44% Solar Dependency
Bldg. With Insulation on glass	$\frac{1530-654}{1530}$ = 57% Solar Dependency

For This Design - Need 845 Ft^2 Collector Area and Storage Tank Size of 1600 Gal.

a) With or without insulation on glass.

Table 10

Total Fuel Requirements[a]

Fuel Source	With Solar Collectors[b] With Window Insulation	With Solar Collectors[b] Without Window Insulation	Without Solar Collectors[c] With Window Insulation	Without Solar Collectors[c] Without Window Insulation
Coal[d] (tons)	4.4	7.3	9.4	12.4
Wood[e] (cords)	15.6[h]	25.5[i]	33.1[j]	43.3[k]
Oil[f] (gallons)	817	1,338	1,737	2,276
Gas[g] (ft^3)	129,662	213,325	275,656	361,152

a) For space heating, methane generator, and hot water requirements.
b) Total Demand with collectors: with insulation - 778[a]
w/o insulation - 1274[a]
c) Total Demand without collectors: with insulation - 1654[a]
w/o insulation - 2167[a]
d) @ 250 therms/ton, 70% furnace efficiency.
e) @ 125 therms/cord, 40% furnace efficiency.
f) @ 1.36 therms/gallon, 70% furnace efficiency.
g) @ 600 BTU/ft^3 (from methane generator), 70% furnace efficiency.
h) Requires 4.2 hectares.
i) Requires 6.9 hectares.
j) Requires 8.9 hectares.
k) Requires 11.7 hectares.

VI. CONCLUSIONS AND DISCUSSION

After evaluating the building's design and analysis, many of the features and concepts incorporated need to be modified and/or further explained.

The amount of space designed seems excessive for the amount of people and activities planned. The two ground floors should be left off completely--two floors of private rooms and one large community space on each side of the building would be adequate. One side could be used for quiet study activities, the other side for recreational activities. The dining area should also be available as a community room to maximize multiple use of spaces. This size reduction would reduce total heat losses and heat requirements. Reducing indoor temperatures to 55° would also reduce heat loss significantly.

The solar collectors should be incorporated into the actual building structure; they would replace the 50° glass on the lower floor of the building. This modification would reduce collector heat loss, piping heat loss and costs, and reduce overall building costs. We originally separated the collectors from the structure to allow more flexibility in the building's design. But this benefit was small compared to the costs involved. The insulated curtains play an important role in reducing large amounts of heat loss through the windows. This strategy for heat loss reduction would only be successful if all community members cooperated by opening and closing the curtains at the necessary times (which may be an unrealistic assumption). Another possible means of insulating the window areas at night is to utilize a "beadwall" (as developed by Zomeworks, New Mexico).[8] This consists of two panes of glass with a space (1-2") between them. When it is desired to insulate the windows, a small vacuum pump blows in many small beads of styrofoam which fills the space between the glass and serves as insulation.

When it is desired to open windows, the vacuum pump reverses, and the beads are removed from the window spaces. The possible negative psychological effects of closing off the windows in the small rooms also needs to be considered. In general, the activities of the members would have a large effect on the actual heat flow of the building i.e. opening and closing, windows and doors, indoor temperature desired, changing the angles on the wooden sun shields, etc. The net heat gains from solar radiation were a very complex component to deal with, due to seasonal and daily variations. As illustrated on Tables 3, and 4-A, H, the amount of solar radiation transmitted through glass fluctuates daily and seasonally due to the changing angles of incidence. Also variations in cloud cover affects the actual amounts and distribution of radiation available. In calculating the daily gains for solar radiation (Tables 4-A, H) average monthly radiation, which accounts for monthly cloud cover, was initially assumed to be evenly distributed throughout all days of the month. An attempt was made to generate a random pattern of solar radiation for different days of a given month (a given amount of days/month in which radiation levels are below average, at average and above average conditions). This analysis became increasingly complex, as it was then necessary to determine the probabilities of various combinations of cloud cover, night and day temperatures and wind speeds, which all interact to determine daily, net heat flow. This type of statistical analysis was beyond the capacity of hand calculations. Instead it was assumed that radiation conditions of 50% below average and 50% above average would occur each for 15 days during each month. Average temperatures and wind speeds were considered uniform throughout the month. When the above and below average radiation levels are tabulated, the monthly daytime losses

appear as a uniform average. The problem of distribution is still somewhat blurred. During days of above average conditions (relatively clear, but not cloudless, days for State College), the building may be subject to overheating or only less heat loss, depending on the month. In a month that has high daytime heat loss, such as February or March, (due to low outside temperatures, high incident angles for most daylight hours, and large amounts of glass shading from overhangs), the occurrance of above average conditions would be useful for offsetting daytime loss, and overheat would not be a problem. During a month with low daytime heat loss, such as November or December (low incident angles results in more of the available radiation being transmitted through glass and less shading of the window areas due to overhangs), above average radiation conditions may result in overheating of the building.

The problem then, is storing this excess heat gain for offsetting nightime heat loss. If windows are opened to relieve overheating, this excess heat would be lost, and the building may be overcooled, which would result in increased heating requirements. The role of interior massive walls with exterior insulation in buffering inappropriate distribution of solar radiation, needs to be investigated (accumulating heat during day time to reduce building overheat, reradiating heat at night to reduce net heat loss). This characteristic of the building could not be evaluated by hand calculations.

During days of below average conditions (complete cloud cover) net day time heat losses and therefore heating requirements would be increased. On days when no appreciable radiation is expected, the insulating window curtains might be kept closed in unused rooms to reduce heat loss. The designed

glass areas used in the building may be excessive and therefore should possibly be reduced to minimize these periodic over heating and cooling effects. The angles of the windows and overhang lengths could be modified to allow more solar radiation heat gains during the late winter months, but this would result in excessive heat gains during the late spring and summer months.

The effectiveness of the solar space heating system would be subject to similar variations in environmental conditions: values and distribution of solar radiation, incident angles, cloud cover, day and nightime temperatures, wind speeds, and the probabilities of different combinations occurring. In addition the heating demand and its distribution also affects the efficiency of the system. If good collection conditions are occurring and the demand on the system is low, then the storage tank temperature will increase. As the temperature in the tank approaches that in the collectors, the efficiency of energy transfer is reduced. If demand on the heating system is constant and matched to the supply of the collector's output, then the temperature difference (between tank and collector) will remain high and energy transfer efficiency will also be high. The performance of solar collectors is so greatly affected by the dynamics of energy demand and environmental conditions, that a complete analysis was not possible with hand calculations. The solar space heating system design and analysis needs much more investigation. More specific data of collector characteristics in this type of climate is necessary before optimal design and dependency for solar heating can be developed; the goal of 50% solar dependency for our design was used only as a guideline (this was adopted from recommendations from some of the architectural engineering faculty). Attempting to supply heat requirements of present housing by utilizing solar energy is probably not a practical or

sound solution. Solar heating systems and the building utilizing them, need to be designed as an integrated system: energy requirements must first be substantially reduced through more careful building design before solar energy can be a reasonable heating alternative.

The use of wood as a back-up (or even primary) heat source has many advantages, but also some disadvantages. Wood is a renewable fuel source and could be produced near the point of use. It provides a low cost system of harnessing solar energy: the energy capturing "machinery" is a self-maintaining and replicating biological system. Pollution would be minimized when correctly burned e.g. wood contains less than .1% sulpher content, the ash is safe to apply back to the woodland, burning wood does not affect the atmosphere's CO_2-O_2 and heat balance (all materials and energy converted into wood are rereleased within a short time), no danger of oil spills, radiation leaks, acid mine drainage, etc.

Wood cannot provide instantaneous, thermostatically controlled supplementary heat as efficiently as gas or liquid fuels. Although highly efficient (compared to typical stoves and fireplaces), thermostatically controlled wood furnaces are available, it is necessary to keep a small amount of wood burning, so that the fire is capable of increasing (increased fuel and air supply) the heat output as needed. This would result in lower, overall conversion efficiency. Wood heat may be difficult to integrate with the variable outputs of a solar system (in this climate). Its use as a constant heat supply seems easily adapted to typical space heating systems. A wood burning system would involve higher maintenance and operating labor requirements. The furnace would need to be attended more often, i.e. loading fuel, emptying ashes. Labor would also be required for cutting, loading and moving

the wood. A small, portable gasoline chain saw could function as an efficient work-gate for securing a large energy flow (wood) for a small input of high grade fossil fuel and labor energy inputs.

Many other areas in building design and construction play key roles in the total concept of low energy housing. We were only able to investigate these superficially: 1) utilizing recycled materials in building construction, 2) use of rubble wall construction so that local stone materials could be utilized without high levels of masonary skills--a wooden form, such as for pouring concrete, is constructed, into this is placed field stone and mortar to produce a stone wall, 3) use of organic insulation materials (corn cob composition board insulation) to reduce energy input for synthetic materials (fiberglass, styrofoam), 4) low maintenance landscape paintings to reduce energy input of lawn mowers, fertilizers, etc. Design of plantings to buffer undesirable effects of climate (shading, coverings, etc.).

In general, we feel that the building's design is fairly sound from a heat flow standpoint. Integrating, the use of many heat flow reduction strategies, resulted in a very low energy requiring building. The entire building requires about as much heat (total demand) as 1 1/2 standard size houses Heating the building by fuels alone would be comparatively inexpensive. Approximately 820 gal. of oil, 130,000 ft^3 of natural gas, or 16 cords of wood would be required (see Table 10). As noted above, various changes in the building, are still necessary to improve its overall performance. Our initial objective of total autonomy allowed us to take a very critical look at building design, and led to the incorporation of many non-conventional, but energy conserving features into the building (eliminating north, east and west windows, south orientation, insulation on windows, etc.--see "Building Syn-

thesis"). The entire building, though, needs to be analyzed for its suitability to the activities planned. Overall building quality (possible fluctuating temperatures, reduced lighting loads) needs to be balanced against the goal of energy autonomy. In addition, investigations into the building's structural characteristics and suitable construction techniques are needed.

It is apparent from the above discussion, that the analysis of a low energy housing design is very complex and not suitable to standard, available engineering methods. Each component of the building needed to be evaluated separately. Evaluating the building heat gains and solar collector behavior with variable factors is very difficult. Our relatively simplified approach to the analysis probably introduced some amount of error into the total heat flow. Better data is needed for evaluating heat loss below grade (accounting for various temperature profiles as one goes deeper).

Two possible strategies may be helpful in evaluating low energy housing. One, is the development of more comprehensive computer programs which can account for large numbers of fluctuating variables. Second, is the designing and actual building of a small proto-type, low energy dwelling (one family unit) that could be monitored and evaluated by the architectural and architectural engineering departments. Only after sufficient data on the behavior of such a building unit under local conditions is produced, could accurate optimizing strategies be employed, complex cost/benefit analysis produced, and finally actual building design guidelines be made available.

The design presented in this project is only a preliminary study of a low-energy dwelling unit. Much more investigation and refinement is necessary before such a structure could actually be built. Many of the design features we utilized, with varying degrees of modification, could be easily

adapted to other housing designs to achieve lower energy requirements. In general the use of complex hardware and technologies to achieve higher building energy autonomy must be kept at a minimum to achieve total low energy housing.

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16" BRICK WALL W/O R-11 INSULATION

	NORTH	NE	EAST	SE	SOUTH	SW	WEST	NW
JAN	-83.6	-83.5	-81.1	-76.8	-74.1	-76.8	-81.2	-83.5
FEB	-71.8	-71.4	-68.6	-64.5	-62.0	-64.4	-68.5	-71.4
MAR	-63.5	-62.3	-58.7	-55.4	-53.9	-55.6	-58.8	-62.4
APR	-45.4	-43.4	-40.3	-38.7	-38.7	-38.7	-40.4	-43.5
MAY	-20.4	-17.6	-14.9 +0.15	-14.6 +0.12	-16.0	-14.5 +0.05	-14.7 +0.05	-17.5
JUN	-4.3 +2.0	-2.9 +4.3	-2.0 +6.8	-2.1 +5.9	-2.8 +3.2	-2.3 +5.8	-2.2 +4.7	-3.0 +4.3
JUL	-3.3 +4.4	-2.3 +7.0	-1.5 +9.6	-1.4 +9.0	-1.8 +7.0	-1.5 +9.1	-1.6 +9.9	-2.4 +7.3
AUG	-4.2 +1.3	-2.8 +2.9	-1.8 5.9	-1.4 +6.6	-1.4 +5.5	-1.5 +6.6	-1.9 +5.9	-2.9 +3.0
SEP	-17.0 +0.1	-15.5 +0.2	-12.5 +0.8	-10.6 +1.6	-9.9 +1.9	-10.6 +1.7	-12.5 +0.9	-15.5 +0.2
OCT	-37.1	36.3	-33.0	-29.1	-27.0	-29.2	-33.1	-36.3
NOV	-62.1	-62.0	-60.0	-56.6	-54.5	-56.6	-60.1	-62.0
DEC	-80.1	-80.1	-78.8	-76.1	-74.5	-76.1	-78.8	-80.1
LOSS	-492.8	-480.1	-453.2	-427.3	-416.6	-427.8	-453.8	-480.5
GAIN	+7.8	+21.4	+23.3	+23.2	+18.2	+23.3	+23.5	+14.8

NOTE: ALL VALUES IN BTU/FT²-HR.

16" BRICK WALL W/R-11 INSULATION

	NORTH	NE	EAST	SE	SOUTH	SW	WEST	NW
JAN.	-24.8	-24.8	-24.1	-22.8	-22.0	-22.8	-24.1	-24.8
FEB.	-21.3	-21.1	-20.3	-19.1	-18.3	-19.0	-20.3	-21.1
MAR.	-18.8	-18.5	-17.4	-16.4	-16.0	-16.5	-17.4	-18.5
APR.	-13.5	-12.9	-12.0	-11.5	-11.5	-11.5	-12.0	-12.9
MAY.	-6.1	-5.2	-4.4	-4.3	-4.7	-4.3	-4.3	-5.2
JUN.	-1.2 +0.6	-0.8 +1.3	-0.6 +2.0	-0.6 +1.8	-0.8 +1.1	-0.6 +1.7	-0.6 +2.0	-0.8 +1.3
JUL.	-0.9 +1.3	-0.7 +2.1	-0.4 +2.9	-0.4 +2.7	-0.5 +2.1	-0.4 +2.7	-0.4 +2.9	-0.7 +2.2
AUG.	-1.2 +0.3	-0.8 +0.9	-0.5 +1.8	-0.4 +2.0	-0.4 +1.6	-0.4 +2.0	-0.5 +1.8	-0.8 +0.9
SEPT.	-5.1	-4.6 +0.1	-3.7 +0.2	-3.1 +0.5	-2.9 +0.6	-3.1 +0.5	-3.7 +0.3	-4.6 +0.1
OCT.	-11.0	-10.8	-9.8	-8.6	-8.0	-8.7	-9.8	-10.8
NOV.	-18.4	-18.3	-17.8	-16.7	-16.1	-16.8	-17.8	-18.3
DEC.	-23.6	-23.6	-23.2	-22.4	-21.9	-22.4	-23.2	-23.6
LOSS	-145.9	-142.1	-134.2	-126.3	-123.1	-126.5	-134.1	-142.1
GAIN	+1.6	+4.4	+6.9	+7.0	+5.4	+6.9	+7.0	+4.5

NOTE: ALL VALUES IN 100 BTU/FT²-MO

8" BRICK WALL W/R-11 INSULATION[9]

	NORTH	NE	EAST	SE	SOUTH	SW	WEST	NW
JAN.	-29.2	-29.1	-28.3	-26.8	-25.8	-26.8	-28.3	-29.1
FEB.	-25.0	-24.9	-23.9	-22.5	-21.7	-22.5	-23.9	-24.9
MAR.	-22.2	-21.8	-20.5	-19.4	-18.8	-19.4	-20.5	-21.8
APR.	-15.7	-15.1	-14.0	-13.5	-13.5	-13.6	-14.1	-15.1
				+0.1	+0.1	+0.1	+0.1	
MAY.	-7.2	-6.4	-5.6	-5.6	-6.1	-5.9	-5.9	-6.5
	+0.1	+0.2	+0.5	+0.6	+0.5	+0.5	+0.7	+0.7
JUN.	-19.6	-14.8	-12.3	-13.2	-16.6	-14.6	-13.9	-16.4
	+1.2	+2.2	+3.1	+2.9	+2.2	+2.9	+3.2	+2.3
JUL.	-1.7	-1.3	-1.1	-1.1	-1.3	-1.2	-1.2	-1.4
	+2.1	+3.0	+4.1	+3.9	+3.3	+4.1	+4.3	+3.3
AUG.	-2.1	-1.6	-1.3	-1.2	-1.4	-1.4	-1.5	-1.8
	+1.0	+1.7	+2.7	+3.1	+2.9	+3.2	+2.9	+1.8
SEPT.	-6.1	-5.7	-4.8	-4.1	-4.3	-4.6	-5.1	-5.8
	+0.2	+0.3	+0.7	+1.3	+1.6	+1.5	+1.0	+0.4
OCT.	-13.0	-12.8	-11.6	-10.4	-9.9	-10.6	-11.7	-12.8
			+0.1	+0.3	+0.5	+0.4	+0.1	
NOV.	-21.7	-21.6	-20.9	-19.7	-19.0	-19.7	-20.9	-21.6
DEC.	-27.8	-27.8	-27.4	-26.4	-25.9	-26.4	-27.4	-27.8
LOSS	-191.3	-182.9	-171.7	-164.2	-164.3	-166.7	-174.4	-185
GAIN	+4.6	+7.4	+11.2	+12.2	+11.1	+12.7	+12.3	+8.5

NOTE: ALL VALUES IN 100 BTU/FT²-MO

8" BRICK WALL

	NORTH	NE	EAST	SE	SOUTH	SW	WEST	NW
JAN.	-159	-158	-154	-146	-141	-146	-154	-158
FEB.	-137	-136	-131	-123	-119	-123	-131	-136
MAR.	-121	-119	-112	-106	-103	-106	-112	-119
APR.	-85.6	-81.9	-76.2 +0.1	-73.4 +0.4	-73.4 +0.4	-74.1 +0.6	-77.0 +0.5	-82.1 +0.1
MAY.	-39.2 +0.4	-34.5 +1.1	-30.7 +2.9	-30.6 +3.1	-33.0 +2.6	-31.9 +3.7	-32.2 +3.4	-35.5 +1.6
JUN.	-10.6 +6.6	-8.0 +11.4	-6.7 +16.5	-7.1 +15.1	-8.9 +11.4	-7.8 +15.1	-7.4 +16.5	-8.8 +11.8
JUL.	-9.0 +11.3	-7.0 +16.2	-5.8 +21.6	-6.0 +20.8	-7.2 +17.5	-6.7 +21.5	-6.6 +22.7	-7.8 +17.3
AUG.	-11.1 +5.5	-8.6 +9.0	-6.9 +14.7	-6.6 +16.4	-7.4 +15.4	-7.3 +17.0	-7.8 +15.4	-9.6 +9.8
SEPT.	-33.1 +1.1	-30.6 +1.5	-26.3 +4.1	-23.6 +6.8	-23.1 +8.4	-24.7 +7.9	-27.4 +5.3	-31.1 +2.2
OCT.	-70.2	-68.8	-62.8 +0.3	-56.5 +1.7	-53.8 +2.7	-57.5 +1.9	-63.5 +0.7	-68.9 +0.1
NOV.	-119	-118	-115	-108	-104	-108	-115	-118
DEC.	-154	-154	-151	-146	-143	-146	-151	-154
LOSS	-948.8	-924.4	-878.4	-832.8	-816.8	-839	-884.9	-928.8
GAIN	+24.9	+39.2	+60.2	+64.3	+58.4	+67.7	+64.5	+42.9

NOTE: ALL VALUES IN 100 BTU/FT²-MO.

INSULATING GLASS U=0.58 S.C.=0.9

	NORTH	NE	EAST	SE	SOUTH	SW	WEST	NW
JAN	-145 +0.4	-144 +0.4	-128 +0.8	-115 +2.8	-107 +4.7	-114 +4.0	-129 +1.6	-144 +0.4
FEB	-111 +0.2	-106 +0.2	-95.3 +1.1	-87.9 +3.9	-80.5 +8.0	-86.7 +7.9	-94.9 +4.0	-108 +0.6
MAR	-90.9 +4.1	-83.8 +6.2	-79.3 +17.6	-75.9 +32.5	-72.5 +47.6	-75.1 +48.2	-77.8 +31.7	-85.4 +10.3
APR	-53.7 +22.4	-49.4 +34.8	-48.5 +64.8	-48.2 +89.0	-48.4 +103	-46.2 +115	-45.7 +91.9	-48.6 +45.9
MAY	-25.4 +69.9	-24.9 +110	-24.8 +161	-25.1 +167	-25.9 +142	-23.6 +174	-22.6 +172	-23.5 +117
JUN	-6.7 +104	-7.0 +156	-7.0 +205	-7.2 +192	-7.3 +150	-6.4 +189	-6.2 +201	-6.4 +153
JUL	-5.8 +115	-6.0 +179	-6.0 +242	-6.1 +231	-6.5 +179	-5.7 +231	-5.6 +246	-5.6 +183
AUG	-8.2 +87.1	-8.2 +154	-8.2 +244	-8.3 +263	-8.6 +225	-7.3 +265	-7.2 +247	-7.5 +154
SEP	-21.0 +50.8	-19.6 +74.7	-19.4 +147	-19.3 +205	-18.8 +227	-18.3 +216	-18.3 +159	-19.5 79.6
OCT	-45.4 +19.3	-42.2 +23.3	-40.1 +65.2	-38.7 +134	-36.3 +194	-38.5 +167	-40.0 +90.9	-43.5 +27.9
NOV	-96.1 +1.9	-94.6 +2.0	-86.4 +8.6	-79.0 +26.7	-74.7 +46.5	-79.2 +39.7	-87.4 +17.0	-95.2 +2.5
DEC	-135 +0.06	-135 +0.06	-120 +0.5	-107 +3.1	-101 +6.1	-108 +5.2	-122 +1.7	-135 +0.06
LOSS	-744.2	-720.7	-663	-617.7	-587.5	-609	-656.7	-722
GAIN	+475.2	+740.7	+1157.8	+1350	+1532.9	+1462	+1263.8	+774.3

NOTE: ALL VALUES IN 100 BTU/FT²-MO.

INSULATING GLASS U=0.58 ; S.C.=0.56

	NORTH	NE	EAST	SE	SOUTH	SW	WEST	NW
JAN	155	-154	-137 +0.35	-123 +2.4	-115 +4.8	-123 +4.2	-139 +1.4	-154
FEB	-126 +0.1	-123 +0.1	-108 +0.6	-97.8 +2.1	-91.9 +4.6	-99.3 +4.5	-111 +2.3	-123 +0.2
MAR	-98.7 +1.7	-89.0 +2.4	-82.0 +8.8	-78.1 +17.8	-75.4 +27.8	-79.5 +27.2	-84.0 +16.3	-92.8 +3.9
APR	-60.2 +9.5	-54.4 +16.4	-52.4 +32.9	-51.9 +44.5	-53.2 +50.1	-52.6 +59.7	-52.8 +49.5	-56.1 +23.8
MAY	-25.0 +37.6	-24.0 +65.8	-23.8 +102	-24.4 +104	-26.0 +84.5	-23.7 +109	-22.7 +110	-23.5 +72.4
JUN	-7.2 +63.8	-7.6 +107	-7.6 +144	-7.8 +130	-8.2 +93.3	-7.1 +128	-6.6 +144	-6.8 +107
JUL	-7.9 +69.9	-8.0 +110	-7.9 +150	-8.1 +141	-8.6 +108	-7.8 +142	-7.5 +153	-7.7 +113
AUG	-8.3 +51.5	-8.1 +84.1	-8.1 +128	-8.2 +137	-8.6 +120	-7.9 +137	-7.8 +127	-8.0 +83.6
SEP	-23.1 +27.5	-21.3 +39.8	-20.7 +79.7	-20.6 +112	-20.8 +123	-20.7 +117	-20.8 +85.1	-21.9 +42.9
OCT	-52.8 +7.6	-49.5 +9.6	-46.3 +29.7	-44.2 +63.5	-42.6 +92.2	-45.4 +80.5	-47.7 +43.1	-51.2 +12.3
NOV	-109 +0.5	-108 +0.5	-95.9 +2.0	-87.7 +10.6	-83.0 +23.8	-89.4 +22.4	-99.4 +92.9	-108 +66.5
DEC								

NOTE: ALL VALUES IN KO BTU/FT²-MO.

SINGLE PANE GLASS U=1.13; S.C.=1.08

	NORTH	NE	EAST	SE	SOUTH	SW	WEST	NW
JAN	-264 +0.1	-262 +0.1	-231 +0.6	-206 +2.8	-194 +4.8	-209 +3.7	-237 +1.0	-262 +0.1
FEB	-240	-234	-199 +0.9	-181 +4.5	-169 +9.8	-183 +9.4	-206 +4 3	-234 +0.2
MAR	-181 +3.5	-166 +4.7	-149 +15.8	-142 +32.9	-137 +54.9	-146 +58.8	-155 +37.7	-171 +10.3
APR	-108 +21.1	-96.0 +33.5	-92.6 +66.5	-92.2 +94.0	-95.2 +110	-94.0 +125	-94.2 +929	-99.9 +47.6
MAY	-45.0 +67.4	-42.6 +110	-42.4 +169	-43.1 +179	-45.7 +152	-42.4 +185	-40.7 +180	-42.2 +119
JUN	-12.0 +120	-12.7 +200	-12.7 +270	-13 1 +244	-14.0 +176	-11.8 +242	-11.2 +269	-11.3 +199
JUL	-12.5 +130	-13.0 +220	-13.0 +304	-13.3 +283	-14.7 +208	-12.6 +284	-12.0 +308	-12.1 +222
AUG	-15.1 +93.7	-14.6 +156	-14.6 +245	-14.8 +267	-16.0 +235	-14.1 +265	-13.6 +242	-14.1 +154
SEP	-35.2 +54.2	-32.0 +76.0	-31.4 +152	-31.2 +216	-31 9 +240	-31 9 +222	-31.9 +160	-33 4 +81.1
OCT	-93.0 +14.1	-86.0 +16.6	-79.6 +61.1	-76.8 +138	-73.5 +201	-79.6 +167	-83.2 +84.3	-90.1 +21.1
NOV	-178 +0,9	-175 +1.0	-154 +5.8	-141 +27,9	-132 +54.0	-143 +46.7	-160 +17.7	-176 +1.2
DEC								

NOTE: ALL VALUES IN 100 BTU/FT²-MO.

SECTION II - FOOD PRODUCTION

I. INTRODUCTION

A. Objectives

The goal of this part of our project was to investigate the design and analysis of an agricultural system to supply the nutritional needs of the community's members, with optimal utilization of required resources. This design and analysis process has several objectives.

1) To evaluate the dynamics and characteristics of a semi-autonomous (i.e. some inputs will be required) food producing system, on the scale of a small community, and to assess the role of such systems in future food production.
2) To define various efficiency measures for agricultural systems, their characteristics, and determining factors.
3) To develop a model to demonstrate the characteristics and interactions of agricultural production factors, and to visualize the efficiency of agricultural systems as these production factors vary.

The agricultural system "design" presented here, is not intended to be a final structure, a finished product engineered for highest efficiency, but as a framework, a process, for organizing the multitude of agricultural production factors and evaluating the efficiency of agricultural systems.

B. Methodology

The basic framework for this section is a systems design and analysis. Agriculture is viewed as a system of resource consuming and producing processes. The overall energy and material resource dynamics of these processes is the focus of this section.

A preliminary background study was made of basic ecological concepts, i.e. ecosystem components and analysis, nutrient cycling, energy flow and trophic structure, homeostasis, productivity, limiting factors, community organization, population dynamics, ecosystems development strategy and characteristics, and systems ecology,[1] for several reasons:

1) Agriculture is essentially a process of manipulating ecosystems to supply a flow of energy to man. Understanding ecosystems would help in fully understanding agricultural systems.
2) The various agricultural processes could be described, organized and evaluated according to these ecological concepts. Although agricultural systems function differently, they do involve analagous processes to "natural" systems.
3) It was thought that contemporary ecological theory might illuminate various ways in which agricultural production might be modified to achieve greater levels of efficiency.

Additionally, a study was made of the factors affecting the global distribution of agricultural systems.[2] It was thought that understanding these locational factors, would give some insights into the factors affecting the efficiency of those systems.

Following this, an investigation was made into the use of energy in food production.[3, 4, 5, 6, 7, 8]

Through these studies, it became apparent that a uniform system to describe various types of agricultural efficiency was necessary, so that different systems could be compared and evaluated.

A model of the factors affecting agricultural production was developed to summarize information gathered in the previous studies.

Finally, a model for a system that would meet the food needs for our proposed community was designed and then analyzed. The design criteria for the food production system was:

1) maximize diet quality
2) integrate the food production system with the shelter, energy, and waste systems
3) utilize local energy and material supplies
4) minimize fossil fuel and fuel requiring production inputs
5) maximize production per unit of land and labor inputs
6) maximize stability, i.e. minimize pest populations and production variability
7) minimize environmental impact, e.g. erosion, pesticide residues.

One of the reasons a semi-autonomous system was utilized for our design and analysis was that within the project's time and capacity, a more accurate and complete model, which accounted for the various agricultural inputs and outputs, could be "built" from a small semi-autonomous system, than if it was "built" from the diverse, complex U.S. food system.

The model presented here is subject to many errors due to the many assumptions, omissions, and diverse information sources utilized in its preparation. Assumed levels of yields, food composition, labor, machinery,

and other inputs and outputs are all subject to variation due to varying environmental and cultural conditions. Although efforts were made to utilize information referring only to Pennsylvania, some general U.S. or regional data was used when specific information could not be found. Because of the many inputs and outputs being modeled, many have been omitted due to lack of information, time and/or oversights. Much of the information utilized is from general estimates made by the project members and people in the various fields. Energy values for the various farm inputs are given as single values, which do not compensate for variations in production methods and transport distance required for the different inputs, and so are easily erroneous. Finally, the model developed is not from measurements of an existing system, but a contrived, hypothetical one. It is not an accurate depiction of some actual situation, but a general illustration of the possible dynamics of such a food production system.

II. GENERAL FRAMEWORK

A. Evaluating the Efficiency of Agricultural Systems

Agriculture is a process which attempts to maximize the conversion of solar energy into products useful and desirable by man. Many diverse resources are utilized in this process: land, sun, wind, water, plants, animals, labor, machinery, fuels, materials, and information. The efficiency of a process is usually expressed as unit output per unit input. Because of the many inputs used in agricultural production, and resulting efficiency levels for them, it is necessary to develop a standardized way of expressing these efficiencies, so that various food production systems can be compared equivalently and completely.

Table 1 is a listing of measures that were used to evaluate agricultural production in this project. Evaluating the efficiency of food production enterprises by a single measure does not provide an adequate illustration of the enterprises' characteristics, and can be misleading as to their relative efficiencies. The majority of these measures (and the subsequent efficiency analysis) are expressed in energy values (Kilocalories). This is done for several reasons:

1) One objective of this project was to assess the types, amounts, and efficiency of energy use in food production.
2) It provides a standardized way of evaluating many diverse types of inputs and outputs.
3) It temporarily separates the various inputs and outputs from distinctions as to their relative contemporary values. An input's economic value may change, but its energy value is constant (the use-

fulness of this concept is limited -- to produce a comprehensive and accurate analysis the various inputs and outputs must be re-evaluated as to their relative values). Separating these values makes it easier to produce the initial analysis. (Following this analysis, the effects of their relative values will be investigated.)

4) It provides a way of illustrating the overall organization, structure, and dynamics of the designed food production system.

A_e (Table 1) represents a variation of a typical agricultural measure -- yield. A_p further qualifies this by evaluating the amount of useable protein for human consumption being produced. These two measures give an evaluation of the nutritionally useful quantities of the foods produced (a more complete evaluation would also include vitamins and minerals produced). S_e, M_e, L_e, F_e, and P_e measure the various input levels into an agricultural system. C_e represents the total of all the cultural inputs (including those not measured by M_e, L_e, F_e, or P_e e.g. irrigation). Z_e and Z_p represent the efficiency of livestock conversion of feed into food. The measures A_{me}, A_{mp}, C_{me}, C_{mp}, L_{me}, L_{mp} are an attempt to express agricultural output/unit input(s) in a useful, easily comparable form. One Kilocalorie Day (Kcal Day) equals the amount of food energy required to supply a person for one day. One Protein-Day equals the amount of useable protein required to supply a person for one day.

Two other "efficiency" measures would be required to make a complete analysis of a food production enterprise. One would evaluate the relative amount of environmental impact a system would have (erosion,

Table 1

Input-Output Measures

A_e - Food Energy/unit area - Kcals/hectare (ha)

A_p - Useable Protein/unit area - Kgms/ha

S_e - Solar Energy Input/unit area - Kcals/ha/6 month growing season

M_e - Machinery Input/unit area - Kcals/ha

L_e - Labor Input/unit area - Kcals/ha

F_e - Fertilizer Input/unit area - Kcals/ha

P_e - Pesticide Input/unit area - Kcals/ha

C_e - Total Cultural Inputs/unit area - Kcals/ha

Z_e - Food Energy/Feed energy input - Percent (animal conversion)

Z_p - Useable Protein/Feed Protein input - Percent (animal conversion)

Production Measures

A_{me} - Kcal Days/unit area - Kcal Days/ha

A_{mp} - Protein days/unit area - Protein Days/ha

C_{me} - Kcal days/Cultural inputs (per 10^5 Kcals of cultural inputs)

C_{mp} - Protein days/Cultural inputs (per 10^5 Kcals of cultural inputs)

L_{me} - Kcal days/Labor input (per 3000 kcals)

L_{mp} - Protein days/Labor input (per 3000 kcals)

runoff, pesticide residues, etc.). The other would evaluate various social factors of a food system (appearance and taste appeal of the foodstuff, adaptability to desired lifestyle, economic feasibility, effects on population distribution, etc.).

B. A General Model of Agricultural Production

Figure 1 represents a model of agricultural production.[2] Although theoretical and unquantified, it provides a framework for organizing the factors interacting in the determination of agricultural systems and their resulting efficiency. This model is presented as an idealized pattern to help evaluate and understand existing and proposed systems.

One approach to the problem of designing a food production system for optimal resource utilization, would be by predictive modeling. In this method, a model such as depicted in Fig. 1, would be quantified for all its components. Then, various combinations of environmental, crop, cultural, and social factors could be tried and the resulting efficiencies measured. The ideal outcome would be that an optimal system could be determined. Aside from the massive technical difficulties required to make an accurate model, the results of such a process would be of questionable validity and usefulness without some predetermined ideas of what characteristics an "optimal" system would possess.

A highly theoretical approach like this was not possible within the skills, background, and time of the project group. Instead, we designed a specific agricultural system, which would embody and illustrate the various components of the idealized model. Table 2 expands on the agricultural production factors used in Fig. 1.

Figure 1

AGRICULTURAL PRODUCTION MODEL

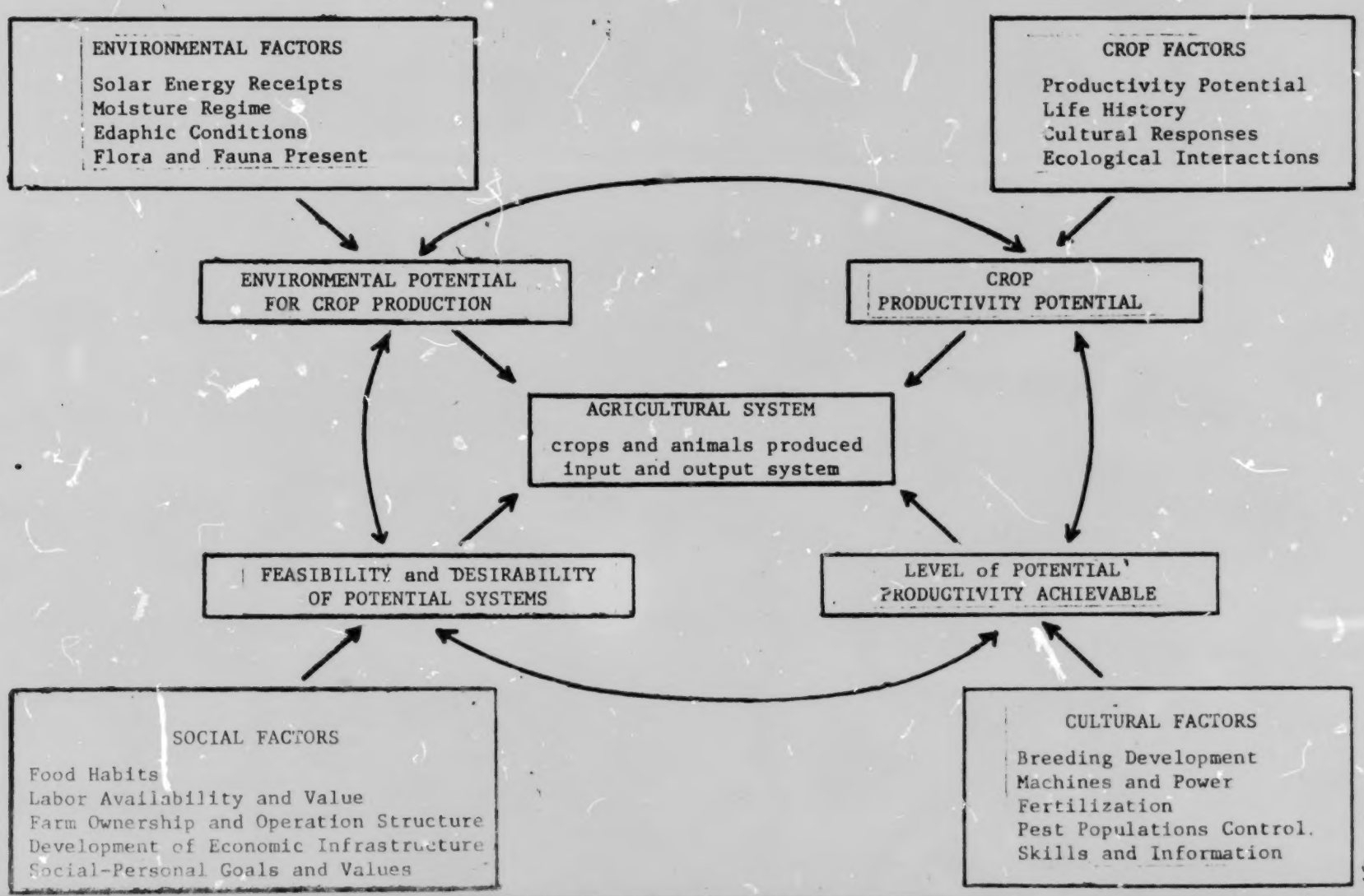


Table 2

Agricultural Production Factors

Environmental Factors

Solar Energy Receipts - amount and distribution
Moisture Regime - amount and distribution, evapo-transpiration rates
Edaphic Conditions - topography, soil depth, texture, structure, drainage, pH, nutrient storage and exchange capacities, soil nutrient levels, organic matter content
Present Flora and Fauna - competing or harmful plants, animal, insect, or microbial pests

Crop Factors

Productivity Potential
1) physiological and morphological capacity of crop plants to capture, convert, and store solar energy as carbohydrates
2) physiological capacity of crop plants to synthesize proteins and vitamins
3) crop plants' moisture, thermal, and nutritional requirements
4) efficiency of protein and energy conversion of domestic animals

Life History - methods, cycles and requirements of reproduction, growth, and maturity
Cultural Responses - responses and adaptions to tillage, planting, fertilization, irrigation, pest control, breeding and harvesting methods, morphological and physiological characteristics of the harvested products
Ecological Interactions - competitiveness, responses to insects, diseases, grazing and harvesting

Cultural Factors

Machines and Power - types and efficiencies of machinery available for field operations (tillage, planting, maintenance and harvesting, etc.), types of energy supplies available, environmental effects of field operations (e.g. soil structure, air pollution)
Fertilization - available materials, methods of utilization and application, environmental effects (e.g. nutrient runoff, effects on soil microflora, etc.)
Pest Control - available strategies and materials, their effectiveness and environmental effects (e.g. wildlife, food residues, beneficial predator and parasite populations, etc.)
Skills and Information - competence of management skills, amount and availability of information in agricultural production sciences

Table 2 (Continued)

Social Factors

Food Habits - preparation and consumption customs and preferences, social unit of procurement, preparation and consumption of food
Labor Availability and Value - organizational structure of labor, relative desirability of various types of "employment"
Farm Ownership and Operation Structure - social organization of production unit control and operation (e.g. families, corporations, etc.)
Development of Economic Infrastructure - development of manufacturing, energy supply, transportation, communication networks, farm supply and service industries, food processing distribution industries
Social-Personal Goals and Values - peoples' general perceived needs and desires from their environment and lifestyle

III. A FOOD PRODUCTION SYSTEM FOR 30 PEOPLE

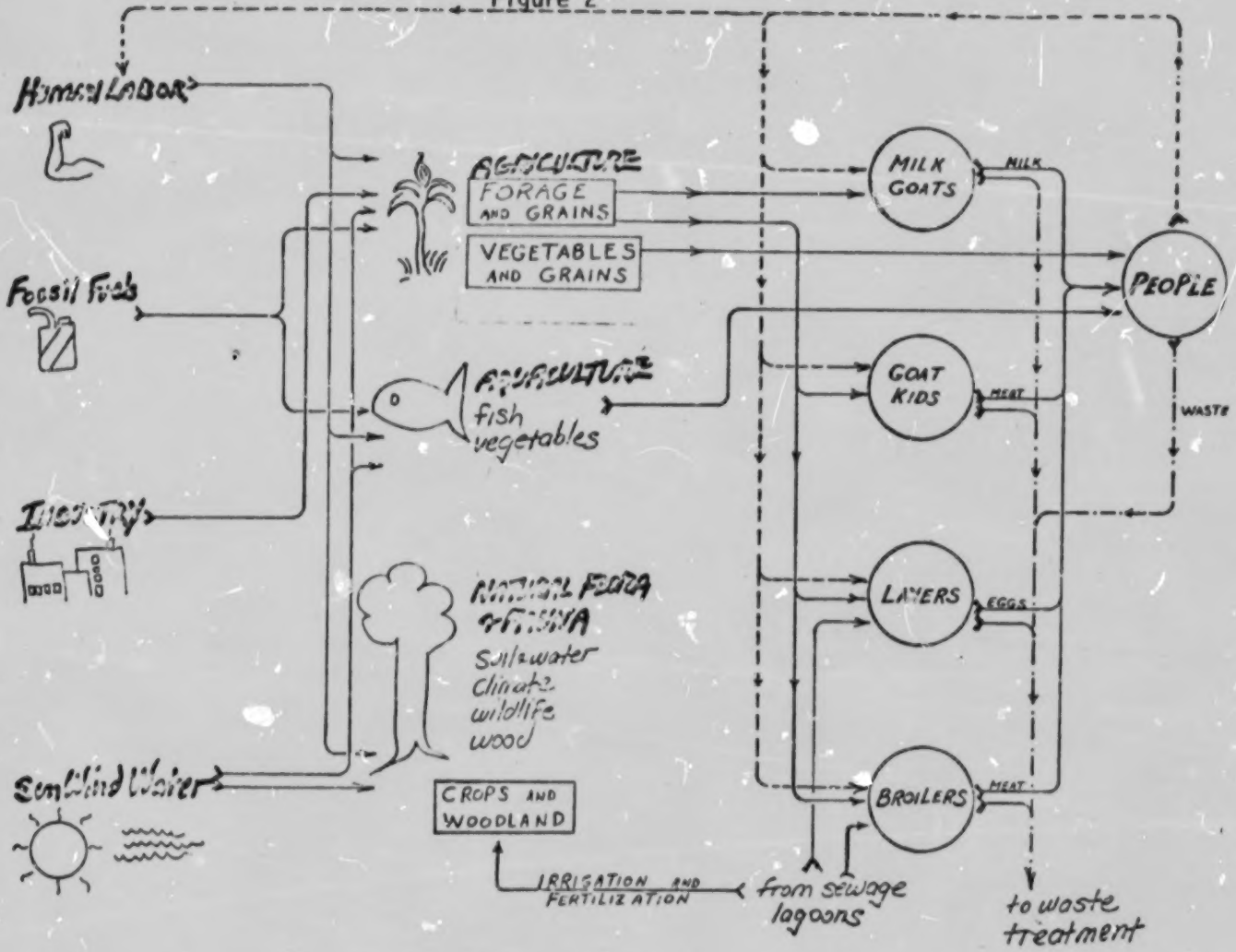
Fig. 2 is a general flow diagram of the food production system developed for a community of thirty people. This overall diagram is presented first to give a unifying framework to all the specific information that is to follow. As information and data are developed (Fig. 3-5; Tables 3-14), the various components of the system will be presented again in quantified forms. Finally the complete system will be presented again in a quantified form, which will depict the major energy and material flows.

A. Nutritional Requirements

The concept of useable protein[9] is used in this model to standardize protein requirements and to make different protein sources comparable. Net Protein Utilization[9] (NPU) is that portion of the total protein content of a foodstuff that is useful to the body. NPU is the combination of digestability and biological value (essential amino acid balance) of a protein source (Fig. 3). Digestability is a characteristic of the protein source, but can be modified by the method of preparation. The amino acid balance is also a fixed characteristic, but can be modified by combining various protein sources at the same meal. Foods vary in their strengths and deficiencies of the essential amino acids; combining two or more protein sources can increase their effective biological value by up to 50%.[9] (Fig. 4). Figure 5 illustrates the types of food complementarity relationships for improving the protein value of plant foods.

Protein requirements in this model are based on the total amount of useable protein for an adult (male and female average). Table 3 is the community's nutritional requirements.

Figure 2



FOOD PRODUCTION

Table 3

Nutritional Requirements

Unit	Calories (Kcals)	Useable Protein
1 person/day	3,000	40 gms[2]
1 person/week	21,000	280 gms
1 person/year	1,095,000	14.60 Kgms
30 people/day	90,000	1.20 Kgms
30 people/week	630,000	8.40 Kgms
30 people/year	328.5×10^5	438.0 Kgms

References

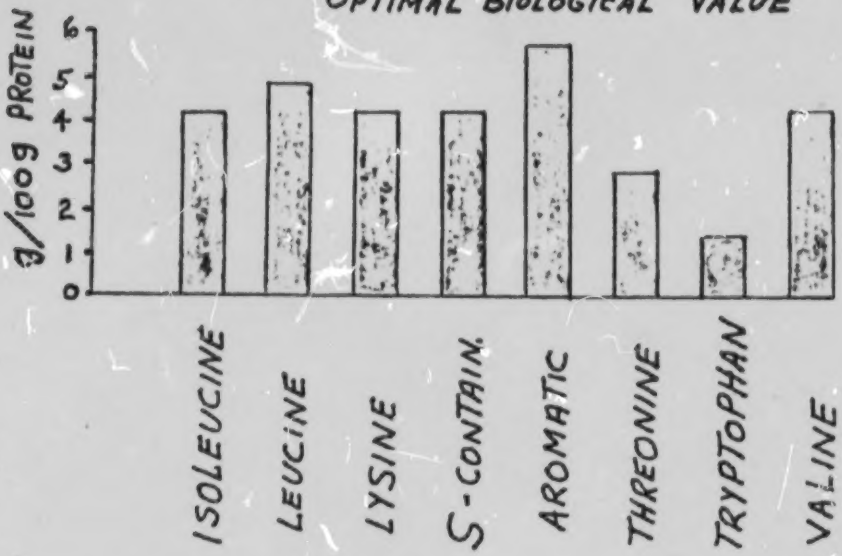
1) National Academy of Sciences, "Recommended Daily Allowances" 1973 - (Figures for adult males 19-22 yrs; active adult females would have about the same requirements).

2) Diet for a Small Planet, Frances Moore Lappé, 1971, p. 43 (.28 gms useable protein/pound body wt.).

FIG. 3

PROTEIN SOURCE

OPTIMAL BIOLOGICAL VALUE

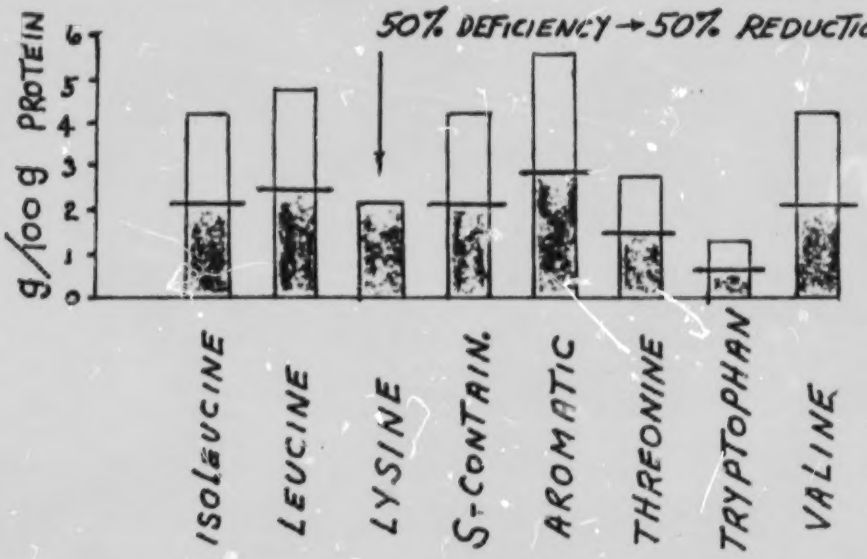


F.A.O. REFERENCE PROTEIN

100% USEABLE PROTEIN (HYPOTHETICAL)

AMINO ACID DEFICIENCY:

50% DEFICIENCY → 50% REDUCTION IN PROTEIN UTILIZATION



BIOLOGICAL VALUE + DIGESTIBILITY → NET PROTEIN UTILIZATION

Figure 4

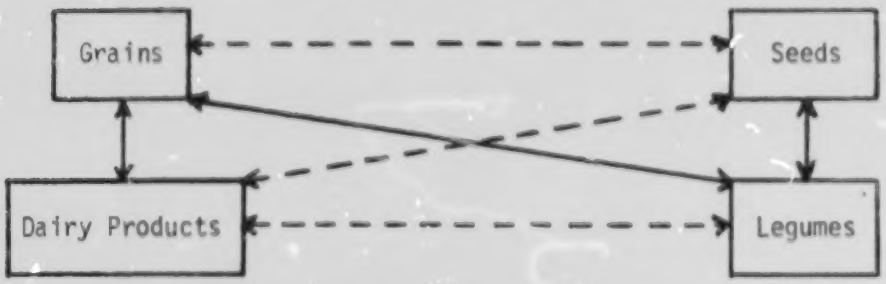
Protein Complementation

Wheat and Beans	Useable Protein Equivalent to:
100 gms beans	57 gms steak
360 gms wheat	142 gms steak
If eaten separately	199 gms steak
If eaten together	265 gms steak or 33% increase in useable protein
Corn and Beans	
100 gms beans	57 gms steak
240 gms corn	43 gms steak
If eaten separately	100 gms steak
If eaten together	150 gms steak or 50% increase in useable protein

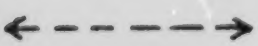
Approximately 240 gms (8.4 oz.) of steak will provide a complete day's requirement of useable protein.

Figure 5

Summary of Complementary Protein Relationships



means complementarily more generally confirmed between several items in each group.



means complementary relationship demonstrated only between a few items in each group.

Table 4

Vegetable Crops - Assumptions and Information

Crop	Yield (Kgm/ha)	Energy[2] Content (Kcals/ Kgm)	Protein[2] Content (Percent)	Energy Production (10^4 Kcals/ha)	Useable Protein Production (Kgms/ha)	Labor[4] Required (hrs/ha)
Storable Vegetables						
Cabbage	17,910	210	2.2%	376.11	197.0	274
Carrots	22,390	420	1.1%	940.38	123.2	600
Jerusalem Artichokes	22,390	410	2.3%	917.99	257.5	321
Onions	22,390	380	1.5%	850.82	168.0	590
Parsnip	17,910	660	1.5%	1182.06	134.3	600
Potatoes	22,390	760	2.1%	1701.64	282.1	321
Pumpkins	22,390	300	2.1%	671.70	235.1	143
Turnip	11,195	230	.8%	257.48	44.8	408
Winter Squash	22,390	500	1.4%	1119.50	156.7	143
Average						
Canned Vegetables						
Beans (Snap)	3,293[5]	180[6]	1.0%[6]	56.66[7]	15.7[7,3]	329[8]
Corn (Sweet)	3,817[5]	660[6]	1.9%[6]	257.99[7]	37.1[7,3]	198[8]
Peas	1,098[5]	660[6]	3.3%[6]	72.15[7]	18.0[7,3]	353[8]
Tomatoes	14,328[5]	210[6]	1.0%[6]	290.05[7]	69.1[7,3]	267[8]
Fresh Vegetables[9, 4]	12,200	288	2.4%	351.10	146.0	400

References

1) "Vegetable Harvest Guide," Dept. of Horticulture, Penna. State University
2) Food Values of Portions Commonly Used
3) Plant protein at .50 NPU, except potato at .60 NPU.
4) "Vegetable Efficiency Ratings," Owner Built Homestead, Vol. I, p. 68, Ken Kern, 1974
5) Yield of quarts/ha: Yields of fresh produce: Beans @ 6,720 kgm/ha, Corn @ Peas @ 2,240, Tomatoes @ 17,910; Yield of canned product from fresh: Beans @ 490 qts/1000 Kgms, Corn @ 560 qts/1000 KGMS, Peas @ 490 qts/1000 Kgms, Tomatoes 800 qts/1000 Kgms (data from: "Canning Fruits and Vegetables," Circular 473, Penna. State University Extension Service
6) Composition of canned solids and liquids[2]
7) Yield of canned solids and liquids
8) Labor required to produce fresh product
9) Average values for assorted typical garden vegetables

Table 5

Field Crops - Assumptions and Information

Crop	Yield[1] (Kgms/ha)	Energy[2] Content (Kcals/ Kgm)	Protein[2] Content (Percent)	Net Protein[3] Utilization (NPU)	Energy Production (10^4 Kcals/ ha)	Useable Protein Production (Kgms/ha)	Total Digestable Nutrients (TDN)
Corn	4,710	4,000	9.5%	.50	1884.00	223.7	80.7%
Wheat (Soft Winter)	2,015	3,265	10.2%	.60	657.90	123.3	
Oats	1,430	3,960	12.5%	.66	566.28	118.0	
Rye	1,880	3,345	12.1%	.58	628.86	131.9	
Barley	1,990	3,500	12.8%	.60	696.50	152.8	78.7%
Buckwheat	1,340	3,330	11.0%	.65	446.20	95.8	
Kidney Beans	2,245	3,430	22.5%	.38	770.04	192.0	
Soybeans	1,010	4,035	36.0%	.62	407.54	225.4	
Legume-Grass Mixture							
Hay	5,600	4,400[5]	15.0%[6]	---	1273.88	0[7]	51.7%
Pasture	22,400	4,400[5]	19.0%[6]	---[9]	2030.34	0[7]	20.6%
Corn-Kidney Bean[8]	3,540	3,828[9]	13.4%[9]	.66[9]	1355.24	313.0	
Wheat-Kidney Bean[10]	2,060	3,301[9]	12.9%[9]	.67[9]	680.32	182.3	

References

1) Values are 1/2 Pa. yield goals (or approx. equivalent to Pa. average crop yields) (1974 Agronomy Guide," Pa. State University Extension Service.
2) Food Values of Portions Commonly Used, Bowes and Church; Morrison's Feeds and Feeding, Morrison.
3) Diet for a Small Planet, Frances Moore Lappé, 1971, pp. 78, 88.
4) "Potential Food Production on Productive Penna. Soils," John B. Washko, Dept. of Agronomy, Pa. State Univ.
5) Communication, Dept. of Animal Science, Pa. State Univ.
6) Personal Communication, John B. Washko, Pa. State Univ. (percentage on a dry matter basis).
7) Useable protein available for human consumption is assumed to be zero.
8) 1 ha = 2474 Kgms corn (.525 ha) + 1066 Kgms beans (.475), complimented at 2.32 Kgms corn to 1 Kgm beans results in 50% increase in useable protein content.[3]
9) Calculated
10) 1 ha = 1612 Kgms wheat (.8 ha) + 449 Kgms beans (.2 ha), complimented at 3.59 Kgms wheat to 1 Kgm of beans results in 33% increase in useable protein content.[3]

Table 6

Laying Chickens - Assumptions and Requirements

Lightweight laying chickens (leghorns) @ 225 eggs/bird/year[1]
Requires: 1) 10.9 Kgms feed/day/100 birds @ 15.5% total protein[2]
2) 2.4 man-hrs/bird/year[3] @ 300 Kcals/hr
3) Vitamin and Mineral Supplement[2]

Produce: 1) 225 eggs/bird/year:
@ 5.83 gms useable protein/egg[4]
@ 78 Kcals/egg[5]
@ 5.66 gms shell/egg @ 96% $CaCO_3$[1]
2) 2.1 Kgm roaster/bird/year (flock replacement)[1]
@ 33% meat, 42% bone, 25% entrails[1]
meat @ 11.84% useable protein, 239 Kcals/100 gms[1]
bone @ 80% $CaCO_3$, 90% Phosphorus, 4% Nitrogen[6]
waste @ 20% protein[1]

Community Requirements:
@ 1 egg/person/day for 30 people = 10,980 eggs/yr[7]
requires - 50 bird flock @ 5.44 Kgms feed/day
Feed Requirements - Layers (@ 25% corn, 25% soybeans, 20% barley, 20% wheat, 10% clover-grass hay)[2]

Feed	Amount (Kgms)	Energy Content (10^4 Kcals)	Useable Protein Content (Kgms)
Corn	496.4	198.56	23.58
Soybean	496.4	200.30	110.79
Barley	397.1	138.98	30.5
Wheat	397.1	129.65	24.30
Hay	198.6	45.18	0.00
	1986.0	712.67	189.17

References

1) Communications Poultry Science Extension, Pa. State University, July 1974.
2) "Farm Poultry Management," Farmer's Bulletin No. 2197, U.S. Dept. of Agriculture, 1972.
3) "Standard Agricultural Labor Demands," Owner Built Homestead, Ken Kern, 1974.
4) Diet for a Small Planet, p. 74.
5) Food Values of Portions Commonly Used.
6) "Analysis of Fertilizing Materials," in 'Soil Testing for the Organic Gardener," Pa. State University Extension Service (values for bone meal used).
7) Estimated use.

Table 7

Milk Goats - Assumptions and Requirements

Require: 1) Feeding
@ .9 Kgms Total Digestable Nutrients (TDN)/day for maintenance[1]
@ .3 Kgms TDN/Kgm milk produced[1]
@ 12.2 Kgms TDN for reproduction[1]
@ .54 Kgms TDN/day as grain during lactation[1]
2) Labor
@ 16 man-hrs/goat/yr[2] @ 300 Kcals/hr
3) Bedding
@ 26.4 Kgms Straw/day

Produce: @ 725 Kgms milk/year[1]
@ 3.2% protein,[3] .82 NPU,[4] 67.1 Kcals/100 gms[3]
@ 305 day lactation, 60 days dry[1]
@ 2 kids/doe/year[1]

Community Requirements: @ .5 Kgm (1 pint)[5]/person/day for 30 people = 5475 Kgms/yr, requires 8 goats.

Feed Requirements: 305 day lactation - maintenance - 274.5 Kgms TDN
- milk production - 217.5 Kgms TDN
60 days dry - maintenance - 54.0 Kgms TDN
- reproduction - 12.2 Kgms TDN
558.0 Kgms TDN/goat/yr

8 goats require - 4466 Kgms TDN/yr

Feed	Amount (Kgms)	TDN (Kgms)	Energy Content (10^4 Kcals)	Useable Protein Content (Kgms)
Corn	162.0	130.7	64.80	7.7
Barley	43.0	33.8	15.05	3.3
Hay (Winter 185 days)	380.9	196.9	86.36	0.0
Pasture (Summer 180 days)	955.3	196.8	86.59	0.0
Total/goat	1540.0	558.0	194.76	11.0
Total/8 goats	12320	4466	1558.06	88.0

References

1) Communications, Dairy Science Extension, Pa. State University, July 1974.
2) "Standard Agricultural Labor Demands," Owner Built Homestead.
3) Food Values of Portions Commonly Used.
4) Diet for a Small Planet, p. 74.
5) Estimated use.

Table 8

Goat Kids - Assumptions and Requirements

Require: Feed - 1) 45.4 Kgms of liveweight grain requires 85.5 Kgms TDN as grain + 200 Kgms TDN as forage[1]
Labor- @ 6 hours/head/year[2] @ 300 Kcals/hr

Production: 1) Kids raised from 4.5 Kgms (3 weeks) to 36.5 Kgms (32 weeks) = 32 Kgms gain/kid[3]
2) Fed first week on doe's milk, then two weeks on commercial lamb milk replacer[3]
3) 14 kids raised/year = 448 Kgms total liveweight gain/year; total liveweight/year = 511 Kgms
4) Liveweight dressing out:
@ 50% meat,[3] @ 18.7% Protein,[4] .65 NPU,[5] 3000 Kcals/Kgms[4]
@ 20% bone,[3] @ 80% $CaCO_3$,[6] 9% Phosphorus,[6] 4% Nitrogen[6]
@ 30% waste, @ 20% Protein[7]

Feed Requirements - 16 Kids

Feed	Amount (Kgms)	TDN (Kgms)	Energy Content (10^4 Kcals)	Useable Protein Content (Kgms)
Corn	1190	960.3	476.00	56.5
Hay (Winter 185 days)	1842	952.3	419.01	0.0
Pasturage (Summer 180 days)	4620	951.7	418.75	0.0
Totals	7652	2864.3	1313.76	56.5

References

1) Morrison's Feeds and Feeding, Morrison (values for fattening lambs).
2) "Standard Agricultural Labor Demands," Owner Built Homestead.
3) Communications, Dairy Science Extension, Pa. State Univ., July 1974.
4) Food Values of Portions Commonly Used.
5) Diet for a Small Planet, (values for lamb used).
6) "Analysis of Fertilizing Materials," in "Soil Testing for the Organic Gardener," Pa. State Univ. Extension Service, (values for bone meal used).
7) Estimated.

Table 9

Machine Energy Inputs

Operation	Power Required[1] (Hp-Hrs/ha)	Fuel Consumption[2] (litres/ha)	Fuel Energy Value[3] (10^4 Kcals/ha)	Capital Energy Value[4] (10^4 Kcals/ha)	Labor Requirement[5] (hrs/ha)	Labor Energy Value[6] (Kcals/ha)
Primary Tillage:						
Moldboard Plow[7]	31.1	12.5	11.93	1.80	2.2	660
Rotary Plow[8]	200.0	80.0	76.63	11.60	33.3	13332
Poto-tiller[9]	60.0	24.0	23.00	3.50	10.0	4000
Secondary Tillage:						
Disking[10]	8.7	3.5	3.32	.50	.7	210
Cultivating:						
Corn[11]	3.3	1.3	1.26	.19	1.0	300
Soybeans[12]	3.2	1.3	1.24	.19	1.2	360
Kidney beans[11]	3.3	1.3	1.26	.19	1.0	300
Planting:						
Corn[13]	2.6	1.0	.98	.15	.8	240
Soybeans[14]	3.1	1.2	1.18	.18	.9	270
Kidney beans[13]	2.6	1.0	.98	.15	.8	240
Small grains[15]	3.3	1.3	1.26	.19	.7	210
Forage[15]	3.3	1.3	1.26	.19	.7	210
No-Till planter[16]	4.1	1.6	1.57	.24	.8	240
Pesticide Spraying[17]	1.7	.7	.67	.10	.3	90
Harvesting:						
Combine-grains[18]	81.5	32.6	31.23	4.73	.6	180
Hay:						
Mowing[19]	5.1	2.0	1.95	.30	.5	150
Raking[f]	2.5	1.0	.98	.14	.5	150
Baling[20]	12.3	4.9	4.73	.71	1.0	300
Handling/metric ton[21]	--	--	--	--	1.0	400
Loose Handling/metric ton[22]	--	--	--	--	1.1	550
Hay Transport/1 Km /metric ton[23]	4.8	1.9	1.84	.28	.25	75

Table 9 (Continued)

References and Calculations

1) Calculated:

$$\text{Required DB Hp} = \frac{\text{Draft (lbs)} \times \text{Speed (mph)}^a}{375}$$

$$\text{Field Capacity (acres/hr)} = \frac{\text{Width (ft)} \times \text{Speed (mph)}^a}{8.25}$$

(@ 100% Field Efficiency later corrected for actual efficiency)

$$\text{Metric Conversion - Field Capacity (hectacres/hr)} = \frac{\text{acres/hr.}}{.4047 \text{ ha/acre}}$$

$$\text{Field Capacity (hrs/ha)} = \frac{1 \text{ hr}}{\text{ha/hr}}$$

$$\text{Power Required (Hp-hrs/ha)} = \text{hrs/ha} \times \text{DB Hp}^a$$

2) Fuel Consumption @ .4 litres/Hp-hr[b]

3) Gasoline @ 9850 Kcals/litre[c]

4) Machinery Capital Value @ 580 Kcals/Hp-hr; Calculated:
@ 244,555,000 Kcals for 13 tons of machinery (tractor and implements) to farm 62 acres of corn[c]
@ 12,000 hrs/useful life of tractor[d]
@ avg. tractor of 46.6 Hp,[c] @ 75% loading[d]

5) Same as machine's field capacity (hrs/ha); corrected later for actual field efficiency, machine set-up, repairs, and maintenance.

6) Labor: @ 300 Kcals/hr for on-machine work
@ 400 Kcals/hr for manual labor
@ 500 Kcals/hr for heavy labor

7) Calculated using: 2-14" bottom plow, draft = 8 lbs/in^2 of soil turned,[e] plowing depth = 6". Speed = 4 mph

8) Calculated using: "Gravely" 7.6 Hp walking tractor with rotary plow attachment, tills an 8" furrow, requires 6 Hp,[f] Working speed - 1 mph[f]

a) Estimated.

9) Calculated using: Garden Type Rototiller, requires 6 Hp, 2 foot working width, @ 1 mph[f]

10) Calculated using: 6 ft. tandem disk, Draft - 160 lbs/ft. width,[a] @ 5 mph[a]

Table 9 (Continued)

11) Calculated using: 2 row cultivator, 36" rows, Draft - 60 lbs/ft,[a] @ 3.5 mph[a]

12) Calculated using: 30" rows

13) Calculated using: 2 row corn planter, Draft - 140 lbs Draft/row,[a] @ 4.5 mph, 36" rows = 2.75 miles row/acre[g]

14) Same as for corn except: 30" rows = 3.3 miles row/acre[g]

15) Calculated using: 7 ft. width grain drill, Draft - 60 lbs/ft. width, @ 4 mph

16) Calculated using: 2 row planter, Draft

17) Calculated using: Sprayer @ 200 gal, 14 ft. boom, @ 5 mph,[a] filled weight - 2100 lbs, Draft = weight x rolling coefficient (rolling coefficient = .2)[a]

18) Calculated using: Combine (custom hired) 12' width, 1 PTO Hp/inch of cylinder width,[a] @ 3 mph[a]

19) Calculated using: 7 ft. mower bar, @ 1 DB Hp/ft + 0.5 PTO Hp/ft,[a] @ 6 mph[a]

20) Calculated using: Custom hired baler, @ 2 Hp-hr/908 Kgms,[a] 5902 Kgms/hr[a]

21) Labor for stacking bales on wagon behind baler, transport, unloading[h]

22) Labor for picking up loose windrowed hay from field by pitchfork, loading onto wagon, unloading from wagon;[h] @ 500 Kcals/hr

23) For transporting loaded hay wagon from field to barn, energy increases linearily with distance (kilometers)[h]

a) "Machinery Performance Data," in "Farm Machinery Management," Agricultural Engineers' Handbook, 1973, pp. 314-320.

b) Communication with Dr. David C. Beppler, Dept. of Ag. Engineering, Pa. State University, February 1974.

c) "Food Production and the Energy Crisis," David Pimental, et. al., Science, November 2, 1973, p. 445.

d) "Farm Machinery Management Guide," Pa. State University Extension Service.

Table 9 (Continued)

e) "Typical Draft or Power Requirements for Selected Farm Operations," Ag. Engineering Fact Sheet - PM-3, Burton S. Horne, Pa. State Univ. Extension Service.

f) Estimated.

g) Handbook for Vegetable Growers, James Edward Knot, University of California at Davis, 1957, p. 23.

h) Personal Communications with Dr. Kjelgaard, Ag. Eng. Dept., Pa. State Univ.

Table 10

Crop Production Inputs

Seed

Crop	Seeding Rate[1] (Kgms/ha)	Energy Value (10^4 Kcals)
Corn	19.6	15.68[2]
Soybeans	78.6	47.57[3]
Kidney beans	67.2[4]	34.57[3]
Wheat	134.3	65.77[3]
Oats	71.6	42.53[3]
Rye	125.4	62.82[3]
Barley	107.5	56.44[3]
Buckwheat	107.5	53.70[3]
Forage	11.2	5.56[3]
Potatoes	2244.0	25.58[3]
Vegetables	---	---

Fertilizers

Nutrient	Energy Value (10^3 Kcals/Kgm)
Nitrogen	18.52[5]
Phosphorus	3.35[5]
Potassium	2.32[5]
Lime (@ 95% $CaCO_3$)	1.46[6]

Pesticides

Type	Energy Value (10^3 Kcals/Kgm)
Herbicides	24.25[5]
Insecticides	24.25[5]

Labor

Type	Energy Value (Kcals/hr)
On-machine; animal care	300
Manual labor; small machines	400
Heavy labor	500

References

1) 1974 Agronomy Guide, Pa. State Univ. Extension Service.
2) Caloric content of seed x 2 (to account for special inputs and care in hybrid seed production).
3) Caloric content of seed x 1.5 (to account for special inputs and care in production).

Table 10 (Continued)

References (Continued)

4) Handbook for Vegetable Growers, James Edward Knot, 1957.
5) "Food Production and the Energy Crisis," David Pimental et. al., Science, November 2, 1973, p. 445.
6) Telephone Communication with Mr. Yost, Plant Chemist, Warner Co., Bellefonte, Pa., (900 tons lime processed requires 320 tons coal and 63,000 Kilowatt hours).

Table 11

Animal Production - Inputs and Outputs

Enterprise	Energy Value (10^5 Kcals)	Useable Protein Content (Kgms)	Area Required (hectares)
Chickens - Layers (50)			
Inputs:			
Feed - 2110 Kgms[1]	75.48	189.8	1.08
Labor - 120 Hrs	.36	---	--
Machinery - 177 Hp-Hrs[2]	7.81	---	--
Labor - 12.5 Hrs[3]	.04	---	--
Total	83.69	189.8	1.08
Outputs:			
Eggs - 10,980 (1200 Kgms)	8.56	64.0	--
Meat - 34.6 Kgms	.83	4.1	--
Total	9.39	68.1	
Milk Goats			
Inputs:			
Feed - 14,050 Kgms[4]	228.23	92.6	1.50
Labor - 128 Hrs	.38	---	--
Machinery - 117 Hp-Hrs[2]	5.16	---	--
Labor - 13.5 Hrs[3]	.04	---	--
Total	233.81	92.6	1.50
Outputs:			
Milk - 5800 Kgms	38.92	185.6	
Kids - 16/year			
Total			
Goat Kids			
Inputs:			
Feed - 8,766 Kgms[5]	147.50	59.5	.88
Labor - 96 Hrs	.29	---	--
Machinery -67.5 Hp-Hrs[2]	2.98	---	--
Labor - 8.4 Hrs[3]	.03	---	--
Total	150.80	59.5	.88
Outputs:			
Meat - 255.5 Kgms	7.66	31.0	
Total Inputs			
Feed - 24,926 Kgms[6]	451.21	341.9	3.46
Labor -378.4 Hrs	1.14	---	--
Machinery -362 Hp-Hrs	15.95	---	--
Total	468.3	341.9	3.46
Total Outputs (food)	55.97	284.7	

References

1) Allows for 5% loss for grains and 14% loss for forage from field to feeding; Corn - 522 Kgms, Soybeans - 522 Kgms, Barley - 418 Kgms, Wheat - 418 Kgms, Hay - 231 Kgms.

References (Continued)

2) Machinery inputs required to produce feed.
3) Labor inputs for feed production.
4) Allows for losses as in chickens: Corn - 1364 Kgms; Barley - 362 Kgms; Hay - 3537 Kgms, Pasture - 8,886 Kgms.
5) Allows for losses as in chickens: Corn - 1252 Kgms, Hay - 2142 Kgms, Pasture - 5,372 Kgms.
6) Corn - 3138 Kgms, Soybean - 522 Kgms, Barley - 780 Kgms, Wheat - 418 Kgms, Hay - 5,910 Kgms, Pasture - 14,258 Kgms.

Table 12-A

Crop Production Summary - Inputs

Crop	Labor Input[1] (Hrs)	Labor Input[1] (10^5 Kcals)	Machine Input[1] (Hp-Hrs)	Machine Input[1] (10^5 Kcals)	Fuel[1] (litres)	Pesticides[2] (Kgms)	Pesticides[2] (10^5 Kcals)	Seed[3] (Kgms)	Seed[3] (10^5 Kcals)	Total Cultural Inputs (10^5 Kcals)
Corn[4]	8.9	.03	134	5.91	53.6	1.4	.34	15.7	1.25	7.53
Soybeans[4]	10.0	.03	117.5	5.19	47.0	.4	.10	55.0	3.33	8.65
Kidney beans[4]	4.6	.01	67.1	2.96	26.8	.2	.05	26.9	1.38	4.40
Winter Wheat[5]	6.0	.02	125.3	5.52	50.1	.3	.07	100.7	4.93	10.54
Winter Barley[5]	6.0	.02	125.3	5.52	50.1	.3	.07	80.6	4.23	9.84
Buckwheat[5]	2.8	.01	58.5	2.58	23.4	--	--	37.6	1.88	4.47
Vegetables:[6]										
Stored	50.5	.20	5.0	.22	2.0	1.0	.24			.66
Canned	110.6	.44	11.9	.52	4.8	2.3	.56			1.52
Fresh	100.8	.40	8.3	.37	3.3	1.7	.41			1.13
Hay (Clover-grass)[7]	13.2	.05	51.2	2.26	20.5	--		12.3	.61	2.92
Pasture (Clover-grass)[8]	2.1	.01	14.2	.63	5.7	--		7.3	.36	1.00
Grass (mulch)[9]	2.6	.01	5.7	.30	2.3	--		2.8	.14	.45
Grass (organic wastes)[9]	5.2	.02	11.4	.60	4.6	--		5.6	.28	.90
Animal Production	344.0[10]	1.03[10]	--[11]	--[11]	--[11]					1.03[10]
Total	667.3	2.28	735.4	32.58	294.2	7.6	1.84	344.5	18.39	55.09
Modified Total										
Complete Total										

Table 12-A (Continued)

Crop Production Summary

References

6) 1/2 of total vegetable production area (.75 ha) cultivated: 1 plowing, 3 diskings (other half in mulch).
7) Field Operations - 1 planting, 3 cuttings, 3 rakings, manual loading and unloading (pitchfork), transport - 1/2 kilometer.
8) Field Operations - 1 planting, 3 mowings.
9) Hand sown (cyclone seeder), 3 cuttings, 3 rakings, manual handling.
10) Labor for animal care only.
11) Machinery energy for feed crop production is pro-rated in Table 11.
12) Area required for amount of crop needed plus waste and surplus.
13) Fresh weight of produce to be canned - yields 1327 quarts.
14) In 4-year rotation with vegetable crops - grows mulch for use on vegetable production areas.
15) In modified 3-year rotation with field crops - used for applying excavated sludge from sewage lagoons and irrigating waste water.
16) Milk Goats, Layers, and Goat Kids, and broilers.
17) Amount of food energy and protein only: feed and grass production not counted.
18) Amount of food available after losses - grain @ 5%, vegetables @ 15%.
19) Accounts for increased useable protein due to food complimentation.
20) Includes area for uncovered fish ponds.

Table 12-B

Crop Production Summary - Output

Crop	Production/year (Kgms)	Energy Produced (10^5 Kcals)	Useable Protein Produced (Kgms)	Area[12] Allotment (hectacres)
Corn	3,768.0	150.72	179.0	.80
Soybeans	707.0	28.53	157.8	.70
Kidney beans	898.0	30.80	76.8	.40
Winter Wheat	1,511.0	49.34	92.5	.75
Winter Barley	1,492.0	52.24	114.6	.75
Buckwheat	469.0	15.62	33.5	.35
Vegetables:				
Storage	3,006.0	14.94	27.3	.15
Canned[13]	2,084.0	4.52	9.7	.35
Fresh	3,042.0	8.78	36.5	.25
Hay (Clover-grass)	6,160.0	140.13	0.0	1.10
Pasture (Clover-grass)	14,560.0	131.97	0.0	.65
Grass (mulch)[14]	1,400.0	31.85	0.0	.25
Grass (organic wastes)[15]	11,200.0	101.52	0.0	.50
Animal Production[16]	7,363.0	57.52	292.4	3.46[20]
Total Production	57,630.0	825.42	1016.7	7.56[20]
Total Food Production[17]	19,482.0	225.45	892.0[19]	7.56[20]
Available Food Production[18]	18,062.0	214.25	857.0[19]	7.56[20]

References

1) From Table for area of crop grown; total amount of machinery energy input (fuel and capital) and labor for all field operations for crop. Machinery energy increased by 15% for field efficiency; labor values increased by 30% for time on machine, set-up and maintenance.
2) 1/2 the average PA usage rate for the crop (Avg. usage from Pa. Farm Management Handbook, energy values from Table , Pa. Avg. Pesticide Usage, Vegetables 13.3 Kgms/ha; Small Grains .9 (herbicides) Kgms/ha; Corn - 3.5 Kgms/ha (Herbicide); Soybeans 1.1 Kgms/ha.
3) Seeding rate and energy value from Table .
4) Field Operations: 1 plowing, 2 diskings, 1 planting, 3 cultivations, and 1 combining.
5) Field Operations: 1 plowing, 3 diskings, 1 drilling, and 1 combining.

Table 13-A

Input-Output Evaluation[1]

Enterprise	A_e[2] (10^5 Kcals /ha	A_p[2] (Kgms U.P. /ha)	L_e[2] (Hrs)	(10^5 Kcals)	M_e[2] Hp-Hrs	(10^5 Kcals)	F_e[2] (Kgms)	(10^5 Kcals)	P_e[2] (Kgms)	(10^5 Kcals)	C_e[2,3] (10^5 Kcals)
Plant Food Production:											
Vegetables:											
Storage	99.59	182.2	337	1.34	33	.15			6.6	1.60	4.4
Canned	12.91	27.8	316	1.26	33	.15			6.6	1.60	4.34
Fresh	35.11	146.0	403	1.61	33	.5			6.6	1.60	4.72
Grains and Legumes											
Corn	188.39	223.7	11	.03	167	7.38			1.8	.44	9.41
Wheat	65.80	123.3	8	.02	167	7.36			.4	.10	14.05
Barley	69.65	152.8	8	.02	167	7.36			.4	.10	13.12
Buckwheat	44.63	95.7	8	.02	167	7.36					12.77
Soybeans	40.76	225.5	14	.04	168	7.41			.6	.14	12.36
Kidney beans	77.00	192.0	12	.03	168	7.39					11.00
Corn & Kidney beans	135.52	313.0	12	.03	168	7.38					
Wheat & Kidney beans	68.03	182.0	9	.03	167	7.37					
Feed Production:											
Corn	188.40	223.7	11	.03	167	7.38			1.8	4.40	9.41
Hay	127.48	0.0	12	.04	46	2.05					2.65
Pasture	203.03	0.0	3	.01	22	.97					1.54
Animal Production:											
Eggs	15.58	63.1	123	.37	164	7.23	Z_e= .12		Z_p= .36		
Milk	25.95	123.7	94	.28	78	3.44	Z_e= .17		Z_p=2.00		
Meat (Chevon)	7.02	28.5	86	.27	103	4.53	Z_e= .05		Z_p= .52		
Total System											
Food Production Only[5]	30.60	122.0	95	.33	105	4.65			1.1	.26	7.87
Food, Waste, & Power[6]	112.04	122.0	95	.33	105	4.65			1.1	.26	7.87
Comparisons											
U.S. Corn Production (1945)	85.44	101.5	23.0	.07		14.88	21.3	1.84	0.0	0.0	22.87
U.S. Corn Production (1954)	103.04	122.3	17.0	.05		23.18	63.9	7.30	.45	.11	38.26
U.S. Corn Production (1971)	203.56	241.7	9.0	.03		33.56	227.7	26.09	2.24	.54	71.58
U.S. Pork Production (1971)	7.63	30.5				33.56	227.7	26.09	2.24	.54	71.58
PA Potato Production (1973)	213.14	353.14	124.0	.50		6.04	555.34	43.06	38.7	20.07	182.87

Table 13-B

Production Evaluation

Enterprise	A_{me}[2] Energy Production Kcal Days	A_{mp}[2] Protein Production (Protein Days)	C_{mp}[2] Cultural Input Efficiency (Kcal Days)	C_{mp}[2] Cultural Input Efficiency (Protein Days)	L_{me}[2] Labor Efficiency (Kcal Days)	L_{mp}[2] Labor Efficiency (Protein Days)
Plant Foods:						
Vegetables:						
Storage	3320	4555	754	1035	496	680
Canned	430	695	99	160	29	47
Fresh	1170	3650	247	773	87	272
Grains and Legumes:						
Corn	6280	5592	667	594	5653	5033
Wheat	2190	3082	155	219	2738	3852
Barley	2322	3820	177	219	2902	4775
Buckwheat	1488	2392	116	187	1860	2990
Soybeans	1359	5638	110	456	971	4027
Kidney beans	2567	4800	233	436	2139	4000
Corn & Kidney beans	4517	7825			4517	7825
Wheat & Kidney beans	2268	4550			2268	4550
Feeds:						
Corn	6280	3801 Kgms		404 Kgms	6280	3801 Kgms
Hay	0	2895 Kgms TDN		1092 Kgms TDN	--	2177 Kgms TDN
Pasture	0	4614 Kgms		2996 Kgms	--	13982 Kgms
Animal Production:						
Layers (eggs & roasters)	290	1578	35	192	22	118
Milk	865	3092	155	554	62	221
Meat (Chevon)	290	881	88	267	27	13
Total System:						
Food Production Only[5]	135	403	17	16	4	12
Food, Waste, & Power[6]	494	403	63	16	15	12
Comparisons:						
U.S. Corn Production (1945)[8]	2848	2538	123	111	501	447
U.S. Corn Production (1954)[8]	3435	3058	89	80	818	728
U.S. Corn Production (1971)[8]	6785	6042	94	84	3051	2717
U.S. Pork Production (1971)[9]	254	763	4	11	156	468
PA Potato Production (1973)[10]	7105	8835	39	48	430	534

Table 13-B (Continued)

1) Date from designed system.

2) See Table 1.

3) Includes seed.

4) Labor requirement increased 3x.

5) Actual available production after waste.

6) Food = 214.25 x 10^5 Kcals
Methane gas = 308.95 10^5 Kcals
Nitrogen value = 264.84 10^5 Kcals
Phosphorus value = 31.82 10^5 Kcals
Potassium value = 27.14 10^5 Kcals
Nutrients are considered an energy asset each time they are recycled. Estimate includes area for uncovered sewage lagoons. These values are not actually calorie day figures (include non-food energy).

Table 14

Diet Summary

Foodstuff-Required/year (Kgms)	Food Energy Supplied (10^5 Kcals)	Useable Protein Supplied (Kgms)	Food Allotment /person/week (grams)	Food Energy /person/week (Kcals)	Useable Protein /person/week (gms)
Grains and Legumes:					
Wheat - 1038	33.90	63.6	665	2,173	41
Corn - 598	23.94	28.4	383	1,535	18
Kidneybeans - 853	29.26	72.9	547	1,876	47
Soybeans - 176	7.09	39.2	113	454	25
Barley - 676	23.67	52.0	433	1,517	33
Buckwheat - 446	14.83	31.8	286	950	20
Vegetables:					
Stored - 2555[1]	12.69	23.2	3,276[4]	813	15
Canned - 1770[2]	3.84	8.2	1,135[4]	246	5
Fresh - 2586[3]	7.46	31.0	3,315[4]	478	20
Animal Products					
Eggs - 1208.0	8.56	64.0	774	549	41
Roasters - 34.6	.83	4.1	22	53	3
Milk - 5800.0	38.92	185.6	3,718	2,495	119
Meat - 255.5	7.66	31.0	164	491	20
Broilers - 65.0	1.55	7.7	42	99	5
System Total	214.20[5]	856.9[6]	14,873	13,730	549
Imports[8]					
Margarine - 182	13.10	--	117	839	--
Oil - 156	13.71	--	100	878	--
Sugar - 234	9.01	--	150	578	--
Apple butter - 156	2.91	.31	100	186	2
Peanut Butter - 200	11.63	23.9	128	746	15
Crackers - 260	11.27	14.2	167	722	9
Macaroni - 52	1.92	3.9	33	123	2
Total	63.55	42.3[7]	795	4,072	28[7]
Total Diet	278.00	900.0	15,670	17,800	577

66

Table 14 (Continued)

1) Cabbage @ 380 Kgms, Carrots @ 200 Kgms, Jerusalem Artichokes @ 335 Kgms, Onions @ 100 Kgms, Parsnips @ 200 Kgms, Potatoes @ 620 Kgms, Pumpkins @ 70 Kgms, Turnips @ 70 Kgms, Winter Squash @ 580 Kgms.
2) Beans @ 172 qts, Corn @ 172 qts, Peas @ 172 qts, Tomatoes @ 610 qts.
3) Assorted fresh garden vegetables.
4) Stored vegetables utilized for 6 months (winter); Fresh vegetables utilized for 6 months (summer); canned vegetables for total year.
5) 65% of community's caloric requirements.
6) Increased by 25% for protein complementation; 200% of community's protein requirements.
7) Not increased for complementation.
8) Allowances from U.S.D.A. recommendations for "Economy-Minded Families" PA-934; Margarine - 3.5 Kgms/week; Oil - 3.0 Kgms/week; Sugar - 4.5 Kgms/week; Apple butter - 3.0 Kgms/week, Peanut Butter - 2.5 Kgms/week; Crackers - 5.0 Kgms/week, Macaroni - 1.0 Kgms/week; for 30 people.

IV. DISCUSSION AND CONCLUSIONS

A. Description and Evaluation of the Designed Food Production System

1) Production - as designed the system supplies 65% of the caloric and 200% of the community's nutritional requirements from 7ha or about 1/4 ha/person (about 1/2 acre/person). Increased high energy supplying crop production (starches, honey) or food energy imports would be required to meet the total demand.

a) Crops - yield levels are approximately the same as current, average Pa. yields (yield estimates for the model were mostly derived from Pa. data). Yields, of course, would be subject to fluctuations (both up and down), depending on the specific year's weather conditions. There are, however, indications of higher yields/unit area in highly labor intensive systems. Greater crop productivity could be achieved by utilizing only the highest yielding crops (calories and protein) within each category, e.g. eliminating the production of canned peas and beans (see Tables 4 and 13-B), substituting barley for winter wheat (see Tables 5 and 13-B), etc. Tables 12-A and B summarize the crop production of the designed system.

b) Animals - egg production/bird is at optimum level because of the low incidence of stress associated with small flock husbandry (i.e. adequate floor space, natural light, free ranging, etc.). High egg production/bird is usually more difficult to maintain in intensively managed commercial laying operations. Overall feed efficiency in the layers is increased

by utilizing the meat (roasters) produced when the flock is replaced (Z_e = .12, Z_p = .36--see Table 13-A). The milk goats have a higher energy conversion efficiency (Z_e = .17) than the chickens, and when their conversion of non-useable (to humans) feed energy is considered (forages) then their actual efficiency of food energy production is greatly increased. For the same type of reason, their efficiency of useable protein production is extremely high (Z_e = 2.00): for every unit of useable protein input, two units are produced. The unique characteristics of ruminant digestion makes these types of conversions possible. One standard dairy cow could easily produce the same amount of milk as the eight goats, with a greater efficiency of feed conversion, but milk goats were utilized because milk production could be maintained at a more uniform level throughout the year (milk production varies greatly depending on the time of lactation, with eight goats the peaks and lows of each goat's production could balance out). Also, it was felt that small livestock would be easier to handle for those community members unfamiliar with animal husbandry.

The goat kids are the least efficient animals in the system (Z_e = .05, Z_p = .52). This is due to the basic inefficiency of energy transfer in food chains from plants to animal flesh. The kids were included in the system for two reasons: 1) they are available as a by-product from the milk production; 2) the amount of meat consumption people are accustomed to in the typical U.S. diet.

Feed conversion for the broilers has not been calculated due to the experimental nature of their feed, i.e. fish meal from the sewage lagoons, but any gain in food production by wastes recovery systems, is an increase in overall efficiency.

In general, the animal production efficiency is in some ways (labor and feed conversion) lower than commercial livestock production because 1) much hand labor is required in small scale husbandry, 2) feed requirements were calculated with allowances for crop losses from field to feeding, and 3) the lower levels of high protein feeds utilized (grains and processed concentrates). The efficiency of the animal production, especially the ruminant animals, could be increased by substituting crop residues, weeds, and low quality plant material for some of the high cultural energy input feeds. In comparing the evaluations of animal and plant food production, it appears that the best way to increase efficiency (for all inputs) would be to eliminate animal production completely. But a closer analysis of the total system of agricultural production (crops and animals) partially invalidates this conclusion. To maintain a continually productive cropping system, some form of rotation, which would include some type of close growing grass and/or legume crop, is necessary (for maintenance of soil structure, pest population reduction, erosion control, nutrient leaching, etc.). Utilizing this forage crop rotation by animals, although poor in their absolute energy and protein conversions, increases the overall efficiency of the whole system by making

food energy and protein (as animal products) available, which, as forage, would otherwise be useless for food. Table 11 summarizes the animal production components of the designed system.

c) Flexibility and Stability of Production - because of the diversity of food production enterprises, an adequate supply of nutrients for the community members is assured, despite fluctuation in crop yields due to varying environmental conditions. The incorporation of the sewage lagoons in the system provides a means of alleviating moisture and nutrient stresses. Also, the grain allotment (corn) for the goat kids can be shifted to human consumption if crop production is extremely poor (1252 Kgms of corn providing an additional 50.8×10^5 Kcals + 59.5 Kgms of useable protein).

2) Production Inputs

a) Labor - this input is extremely variable depending on the production enterprise and its level of mechanization (see Tables 4, 5, 6, 7, 8, 13-A). Returns to labor (L_{me}; L_{mp} on Table 13-B) are extremely high for the mechanized field crops, moderate for the vegetable crops, and low for the animal production. This efficiency could be increased by utilizing only the most productive and lowest labor requiring enterprises, e.g. reduced animal production, selection of the most labor efficient vegetables--pumpkins, squash, etc. Utilizing labor instead of machinery greatly reduces the total amount of cultural energy (C_e - Table 12-A) required for crop production, e.g. vegetable production, hand harvesting of hay (Table 9).

The calculated labor requirements (Table 12-A) seems much too unrealistic and is probably subject to an extreme degree of inaccuracy. In general, it is extremely difficult to assess all the labor demands of such a system. The labor requirements assumed for the vegetable production (Table 4) are probably somewhat low (the original reference for these requirements, does not explain how these requirements were derived). The calculated labor requirement does not account for fluctuating requirements with varying yield levels, pest populations, etc., for the general maintenance of the land and buildings, for food processing, storage and preparation, and for increased requirements due to lower levels of mechanization for grain harvesting (see next section--"Machinery"). It seems quite reasonable that the labor requirements should be increased many fold, but even if increased ten-fold, the labor required per person/year is still quite low (222 Hours/person/year). Extremely strenuous tasks, for example hay and sludge loading, which require large amounts of labor/unit time, could be handled by a group of community members (possibly the whole community). This would reduce the amount of time and exertion required per individual for a certain task. Also, a large proportion of this labor is required at several peaks during the year, so much time in-between would be available for members to pursue other activities. Integrating the labor requirements of food production with other pursuits (research, education, etc.) reduces monotony and boredom, and makes for more effective utilization of labor.

b) Machinery - in general, using large machinery designed for commercial agriculture on such a small area (7 hectacres) is not an efficient or economic use of resources. The small field sizes and availability of labor in the designed system, makes the relatively large capacity of a two-bottom plow and tractor (a 20 Hp Unit @ 75% loading is required) difficult to justify; utilizing a one-bottom plow and a smaller tractor (of 8-12 Hp) appears more justifiable and feasible. This change would increase the labor requirements for plowing by 2x (from 13 hrs/season to 26 hrs/season). A somewhat smaller size tandem-disk and mower bar would also be necessary (also increasing the labor for these field operations). The other field machinery i.e. planter, cultivator and side-delivery rake, could remain as initially designed. The smaller size tractor would have sufficient power capacity for these implements (see Table 9 references). Using these size implements would provide closer loading of the tractor's power capacity (50-75%) with resulting better fuel efficiency. The high energy and labor requirements of the smaller tillage machinery (rototiller and "Gravely" rotary plow (see Table 9) makes the use of these very inefficient. Without the use of fuel powered machinery for tillage, labor requirements for the system would be prohibitive.

Because of the large energy input and field capacity of a modern combine (grain harvester - Table 9), its use in such a small system is not efficient or economic. Manual harvesting of hay and ear corn is much more feasible considering the amounts

of labor available. For small grain harvesting, some intermediate technology between totally mechanized and totally manual methods (e.g. stationary thresher, field binder, etc.) seems necessary to provide an optimal balance between labor and machine efficiency and capital investment. All the components of machine energy input--labor, fuel, and capital--need to be evaluated for a complete analysis. The total "costs" (energy, materials, money) of utilizing industrially produced machinery, including the energetic, monetary, social, and ecological costs of industrial production, need to be carefully and fully analyzed.

c) Nutrient and Soil Management - considering the high energy costs (Table 10) for producing and transporting commercial fertilizers, the internal recycling of nutrients within the system is very desirable. After the initial input of fertilizers to begin production, the amount of nutrients available from the sewage lagoons would be more than adequate to maintain the necessary levels of crop production. (N-204 Kgms/ha, P-135 Kgms/ha, K-167 Kgms/ha, see Sec. III "Organic Wastes System" Table 2 .) According to the wastes system's calculated flow, the amounts of nutrients available in the lagoons would be excessive if completely applied only to crop land. Excess amounts would need to be spray irrigated onto the woodland area(s) (living filter).

Nutrients from the lagoons would be available in two forms: 1) dissolved in the water of the lagoon, 2) organic complexes in the settled sludge and aquatic biomass. Dissolved nutrients would be applied by spray and/or surface irrigation; organic

solids would be excavated from the lagoon after draining, and spread onto areas to be used for field crops. The sludge might also be aerobically composted, with additional plant material for use on the vegetable crops. Aquatic biomass (phyto and zoo plankton, insects, small fish, etc.) would also supply organic material and nutrients.

Spray-irrigated effluent would provide a continuous source of nutrients and moisture for crop growth throughout the season. Annual applications of organic solids (sludge and biomass) from excavated lagoons, would result in improved soil structure, slow-releasing forms of the major and minor plant nutrients, increased microbial activity, increased soil nutrient holding capacity (cation exchange capacity) and improved availability of phosphorus (phosphorus in organic complexes become available for plant utilization much quicker than phosphorus in complex with soil minerals). The need for lime inputs would be reduced by the use of wood ashes from the building's wood heating system. Concentrated forms of calcium, phosphorus, and other trace minerals from bones and eggshells, would be available for feeding to livestock (mineral supplement) and use on fields.

The field crops would utilize a modified 3 year rotation: rowcrops (corn, kidney bean, and soybean), then small grains (wheat, barley, buckwheat, etc.), then a grass-clover mixture seeded into the small grain. Each year the area that was in forage production (the previous year) would be plowed for row crops. Also a portion of the grass area being utilized for

sludge and effluent disposable would also be plowed for row crops and an equivalent amount of forage producing land would be put into wastes disposal. The vegetable crops would be on a separate 4 year rotation consisting of four 1/2 ha plots, 3 of which would be in production and one would be in a grass-legume cover crop for mulch during any one year.[a]

The use of a detritus food chain (organic wastes decomposition) allows for multiple use and recycling of nutrients. This integration of aquatic and terrestrial ecosystems would help increase the overall stability, diversity and productivity of the entire food production system.

The energy (machinery and labor) and capital requirements for the digestor, and pumping and spreading of the effluent and sludge were not calculated due to the experimental nature of the systems and subsequent lack of data. These costs must be evaluated to determine the true costs of the entire waste-nutrient-energy system. Also careful management of the system is necessary to prevent human health hazards, crop damage, or disruptions to the local ecosystems (see section III).

d) Pest Control - it was not feasible to evaluate all the possible pest problems which might be associated with any of the different production enterprises. The value of such a study would be doubtful - individual pest control measures are already available in other sources. Instead a general survey of basic pest population control strategies was made, which would integrate many different concepts of pest management that might be utilized

a) The four ponds for waste treatment brings the total land required to 7.6 ha (see Section III - Table 3).

to help achieve the design goals of the food production system i.e. minimized energy inputs and ecological disruptions. Also, the designed community has several unique characteristics, which lends itself to more effective pest management.

The diverse cropping systems utilized reduces the community's dependence on the production of any one crop for an adequate food supply, therefore increasing its ability to tolerate crop losses. Also this diversity of cropping (polyculture) will reduce the abundance and spread of any one pest species, and would be more adapted to the use of non-chemical pest control strategies. The availability of water and nutrients throughout the growing season from the sewage lagoons would help alleviate plant stresses when these grown factors become limiting. Plants are more susceptible to some pest when under these types of stresses. Also a plant's resistance to certain diseases can be increased by applying nutrients in a more uniform rate throughout the growing season. The availability of spray irrigated nutrients and slow-release, organic nutrient sources from sludge application, could provide such uniformity. In addition the large amounts of organic matter being applied from sludge, aquatic biomass, mulches, and forage crops will increase the activity of soil microorganisms and therefore microbial antibiosis which would help reduce some soil associated pest problems.

With agricultural faculty and students as part of the community, an interdisciplinary group would be available to manage the food production system to assure proper plant, soil, and

pest control methods for minimizing pest problems. Proper plant management would include: optimum plant spacing to provide adequate aeration and light exposure, use of rotations, crop refuse sanitation (digestion and composting, burning) and weed control to reduce pest populations; proper site selection (drainage, sunlight, soil depth etc.) and utilization of locally adapted crops and varieties to assure optimum growth; use of available resistant and tolerant crops and varieties to minimize pest damage; interplanting of crops and successful plantings (early and late crops and variations) to increase the diversity; proper methods and timing for the various field operations: tillage, planting, cultivating, irrigating, harvesting, etc., eliminating alternate hosts for pests, and reduced emphasis on crops and varieties with difficult pest problems.

Proper soil management would include: maintaining optimum nutrient, pH and moisture levels, developing soil structure by applications of organic and crop rotations to improve, aeration, moisture infiltration and storage, nutrient storage and exchange capacity, micro and macro soil organism activity, and utilizing mulches (on vegetable crops) to reduce weeds and maintain optimum soil moisture and temperature, which will all help to assure optimum conditions for vigorous crop growth. Proper pest management would include: proper selection, rate, timing and application of pesticide materials to reduce pest populations and minimize effects on non-target organisms and systems; continual monitoring of crop growth, pest and beneficial organism popula-

lations, and micro-climatic conditions (temperature, humidity, etc.) to determine the need for pest control techniques, keeping records on previous cropping practices and environmental conditions in order to predict pest problems.

The cropping system would be divided into two aspects: subsistence and experimental. On the subsistence crops (those needed to provide the basic nutritional needs of the community) pest populations will need to be closely controlled to assure an adequate food supply. Chemicals (at present) would need to be the key control method for some pests and the only feasible control for others. They would be used for suppressing normal fluctuations in pest populations which exceeded the regulatory capacities of biologic (natural and introduced) agents and cultural control practices. They would also be used as preventative control measures and for initial reduction of pest population densities, so as to make other control methods effective and feasible. In selecting chemical controls the following criteria would be utilized: 1) minimal residue on crops, 2) high specificity (to target organism(s), 3) low toxicity, especially to mammals, fish (sewage lagoons) and birds, 4) minimal movement in the environment, 5) low persistence (easily broken down in the environment) (for example botanical insecticides, methaxychlor, etc.). The control strategy would be to integrate physical biological, natural and chemical methods to minimize harmful effects on non-target organisms and systems, and minimize inputs of energy-expensive pesticide materials. All aspects of a pest's

life cycle needs to be exploited to suppress survival, reproduction and multiplication. The large amount of labor available allows the use of labor intensive pest control methods e.g. spot spraying, insect traps, manual cultivation and insect removal; it also allows for a high level of contact with the food production system(s) which would result in a high intensity of pest management, i.e. continual pest population, crop and weather monitoring. Both of these strategies would be helpful in minimizing the amounts of chemical pest control necessary. The experimental crops would be used for evaluating and developing alternative pest control methods. Depending on the effectiveness of these methods the community would have some amount of extra food available for selling, eating or increased animal production. Some particular areas of investigation might be:

1) evaluating the actual control effectiveness and mechanisms included in the ecological design of the cropping system e.g. interplanting and companion planting (attractants, repellants, and masking mechanisms), trap crops, smother crops, plant allelopathic substances, management of non-crop vegetation for refuge, nutrition, and reproduction of beneficial organisms, etc.;

2) developing and evaluating low input-requiring, on-site, biotic regulatory agents e.g. introduced and natural predators, parasites and diseases of pest organisms (lady beetles, parasitic wasps and flies, bacterial fungus, and virus diseases, arachnids, dragonflies, etc.), use of macro-predators (chickens, geese, ducks, insectivorous mammals, amphibians, reptiles, etc.);

3) evaluate behavior modifying chemicals e.g. pheremones (sex attractants, feeding inhibitors and stimulants), hormones, secondary plant exudates, etc.;

4) developing and evaluating local varieties and adapted crops which have minimum pest problems.

e) Other Interactions - although production efficiency may not be as high as commercial-scale agriculture, the distribution efficiency of the system is high because of the reduced requirements for transport, storage, and marketing. The on-site energy requirements for storage are low because of the relatively small amounts (per capita) of refrigerated and frozen foods. Most of the food is either stores dry (grains and legumes) or in an underground storage cellar (potatoes, onions, carrots, cabbage, etc.). Some vegetables could be stored right in the garden areas e.g. cabbage, parsnips, carrots, etc. Eggs and milk would require daily refrigeration, and the layers would need to be frozen after butchering. The goat kids and broilers would be fattened on a staggered schedule, so that whatever is butchered, could be eaten within a couple of days and therefore not requiring freezing space (goat butcherings could be a special occasion, necessitating a community celebration-feast to consume the meat quickly). Fish produced in the intensive (attached to building) ponds (Tilapia spp.) could remain in the ponds after the summer growing season, and removed when needed. (See Appendix I)

The diet produced by this system will be of high quality: low content of refined sugars and starches, and pesticide resi-

dues (due to eating low on the food chain[9]). According to some nutritional authorities an egg/day for an adult male may result in excessive cholesterol levels. Because of the above reason and the excess of protein production (856 Kgms), the amount of egg (and possibly milk) production should be reduced (which will also result in greater overall production efficiency).

To fully evaluate the production efficiency of the designed system, it must be viewed as part of an integrated food, waste, nutrient and energy system. The total value of waste treatment, fertilizer, energy (methane gas), and food production must be considered.

3) Education and Research - a food production system of this type and scale would be highly useful for many types of educational and research applications in regards to agricultural production. Students and faculty could be involved with the whole range of activities associated with all phases of food production: soil, crop, animal, pest, and machinery management, food processing storage and consumption. In doing this one could integrate the total system of food production with his/her own specialty and develop an understanding and appreciation for all the other disciplines involved. Students and faculty unfamiliar with agriculture could gain some practical experience and understanding of the various processes involved in food production. In both cases the students and faculty would be in direct contact with an actual (although somewhat different from commercial production) food production system, rather than studying it academically in many separate class rooms.

The system would also provide a unique opportunity for interdisciplinary research. The people involved could always be looking at the system as an experiment: continuously evaluating present methods, and developing new methods for the food production system. The investigations would be carried out in a hybrid system: not strictly an experimental or production system, and therefore it could integrate the important characteristics inherent in each type. Also, all investigations would take place in a whole system: any interactions and effects with one aspect resulting from changes in another aspect of the system would be easily apparent (or somewhat easier than when they are studied in isolation of each other).

Research could be directed towards investigating low energy-requiring cropping systems, developing small scale production machinery and technologies, and investigating the role of social-psychological factors that effect food habits and production technologies.

Emphasis would be placed on developing low industrial input-requiring high output food systems e.g. outdoor and greenhouse fish production (see Appendix I), aquatic plants (cattails), outdoor and greenhouse vegetable production, utilization of weed plants (lambsquarters, violets, pigweeds, etc.) for feed and food crops, etc. They could investigate small scale machinery and technologies for production, harvesting, processing, and storing foods that are low energy and materials requiring. Also the actual labor requirements and efficiency of small scale production could be evaluated. On going social and psychological experiments could be conducted on:

the acceptability of more efficiently produced foods (less animal products, new foods--fish, "weeds," etc.), willingness to tolerate more pest damage, methods of organizing labor for food production, etc.

B. General Analysis and Development Strategies for Agricultural Production

1) Analysis Strategies - through our processes of designing and analyzing a small food production system, the entire concept of food production efficiency has become quite complex. An agricultural enterprise may simultaneously have a high efficiency for one measure but a low efficiency for another. Because of the increasing costs of all resources, some means of evaluating and ranking these various efficiency levels are needed so that present and proposed agricultural systems can be evaluated as to their short and long term feasibility and desireability. In developing such cost/benefit analysis the total energetic, economic, ecologic, and social "costs" and "benefits" need to be evaluated. The whole concept of energy analysis needs further development and refinement. In comparing various inputs and outputs in terms of their absolute estimated energy values, many important characteristics of a particular system are illustrated, but many are also obscured. The relative values (for people) of the inputs or outputs are disregarded. For example, when considering the energy values of a machine input to a labor input, the difference between them may appear so great, that the importance of the labor input appears very small. A labor input of only a few thousand kilocalories represents a full day's labor for a person, whereas a machinery input of hundreds of thousands of

kilocalories may only represent an hour or two of machine time; a given machinery input which uses a certain amount of gasoline may be replaced with a chemical input which has a higher energy value (for synthesis and transport) than the original amount of fuel required to do the same job mechanically--but the energy for manufacturing may come from coal generated electricity which may be of less value/kilocalorie than a kilocalorie of imported liquid fuel oil; although some amount of coal may have the same energy value as a kilogram of wheat, the coal's value as useable food energy is zero. The relative values of different outputs can also be similarly evaluated (1000 calories of wheat vs. 1000 calories of steak, etc.). The concept of diminishing returns seems to be a generalized principle for most production inputs. Evaluation methods for determining the key production inputs, and their optimum levels and timing to obtain maximum returns per unit of input, would be useful in developing complete cost/benefit analysis for agricultural systems. Computer programs, which could account for all the different factors affecting production and also analyze efficiency in many ways simultaneously, would be useful in developing predictive models for agricultural systems (see I-B--"A general model of agricultural production").

2) Development Strategies - many of the specific strategies utilized in our semi-autonomous design, e.g. increased use of plant proteins, waste water recycling, increased use of labor, etc., are applicable in modified forms to other agricultural systems as a means to reduce energy inputs. In addition the general concept of semi-autonomous

food production (integrated food, waste and energy systems) can be employed to existing and proposed communities as a means to increase agricultural efficiency, diversity, and stability. For example: develop on-site food production of existing suburban-urban properties (backyard micro-farms--intensive horticultural, small animal, and aquatic production, integrated with on-site waste and energy sources); develop regional food-waste-energy systems for existing metropolitan centers (regional agricultural and resource recovery complexes, incorporating field crops, animal, aquatic, horticultural and woodland production, integrated with existing waste treatment, energy and transport systems, and labor supplies); develop semi-autonomous food systems for small housing developments, apartments and condominiums (utilizing common open spaces and community and labor); develop rural-urban food cooperatives: decentralized food producing communities integrated with urban food marketing and retailing cooperatives; together they would supply and organize the capital, labor, skills, information, and inputs required for the complete food production, processing, storage and marketing system. This increased rural-urban integration would allow for more multiple-use of resources, effective land use planning, and cultural diversification.

In general, the emphasis should be on developing a broadly based, regionally adapted, low energy and materials input, integrated food supply system which is dynamic in operation to allow for fluctuations in the biological, physical, and social environments.

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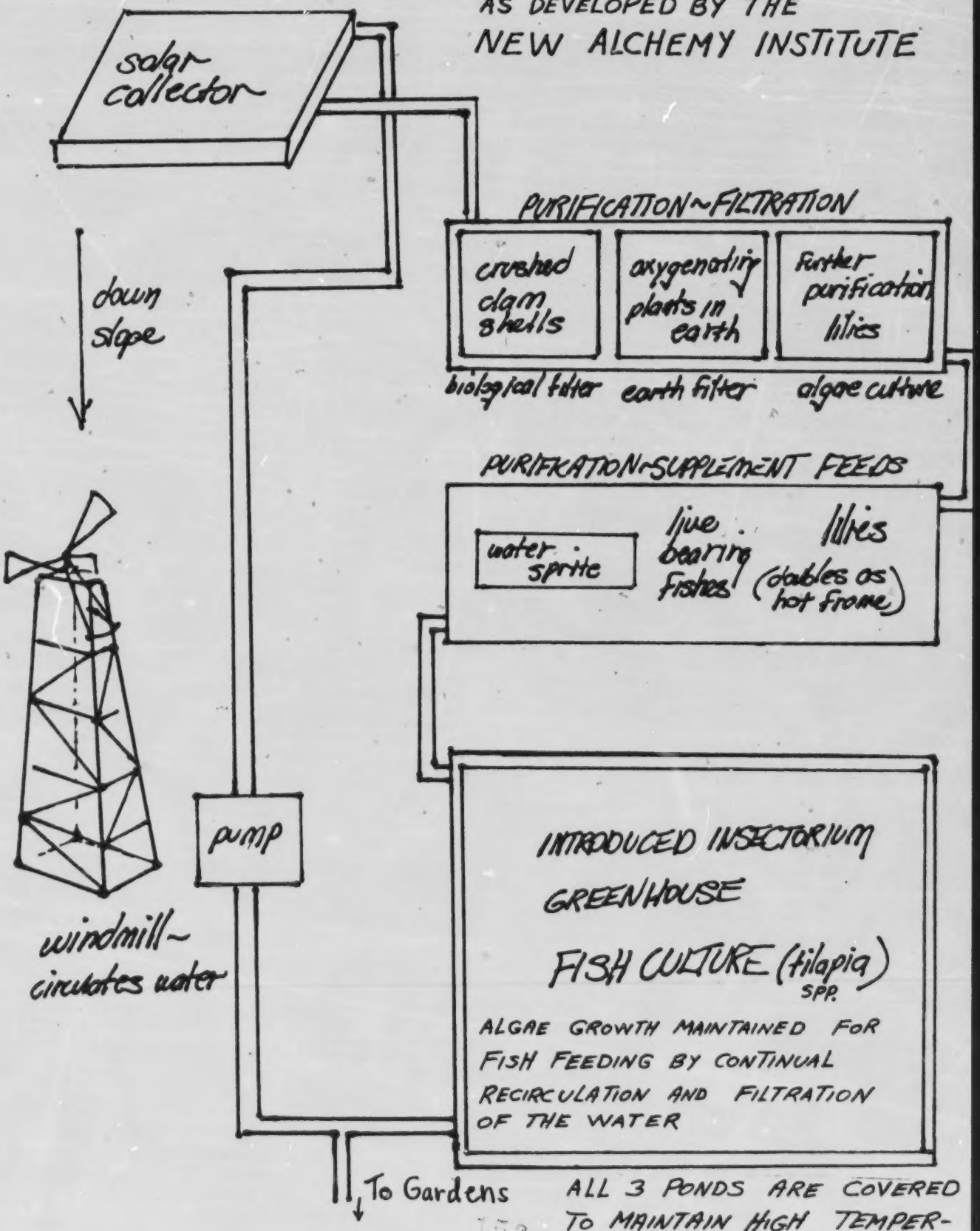
APPENDIX I

AQUACULTURE

AS DEVELOPED BY THE
NEW ALCHEMY INSTITUTE

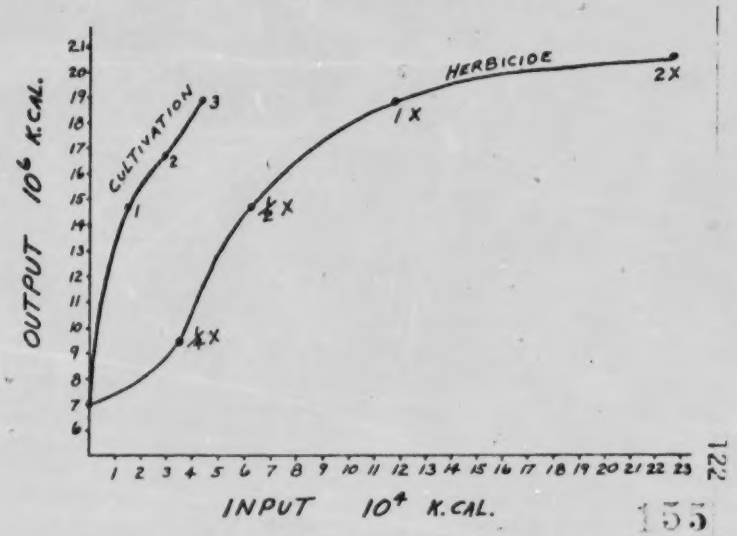


ALL 3 PONDS ARE COVERED TO MAINTAIN HIGH TEMPERATURES

Appendix II

Weed Control - Input-Output Analysis

Treatment	Inputs (10^4 Kcals) Machine	Capital	Labor	Chemical	Total	% Increase	Weed Control (Percent)	Output (10^4 Kcals) Yield[1] (2096 x 10^4 Kcals)	Response[2]
No Treatment	0.00	0.00	0.00	0.00	0.00		0.0	698.66	
1 Cultivation	1.26	.14	.04	0.00	1.44	100.0	70.0	1467.20	1.10
2 Cultivation	2.51	.29	.08	0.00	2.88	100.0	80.0	1676.80	.14
3 Cultivation	3.76	.44	.12	0.00	4.32	100.0	90.0	1886.40	.12
Herbicide @ 1/4 rate	.67	.08	.01	2.73	3.49	100.0	30.0	943.20	.35
Herbicide @ 1/2 rate	.67	.08	.01	5.46	6.22	78.2	70.0	1467.20	.71
Herbicide @ rate	.67	.08	.01	10.91	11.67	87.6	90.0	1886.40	.33
Herbicide @ 2 x rate	.67	.08	.01	21.82	22.58	93.5	98.0	2054.08	.01



SECTION III - ORGANIC WASTES SYSTEM

I. SYSTEM DESIGN

The goal of this section was to design and analyze an integrated waste-energy-nutrient system which would handle all the organic wastes of the community. The three main components of the system are: 1) Methane Generator (Anaerobic Digestor), 2) Sewage Lagoon Pond Series (Advanced Biologic Waste Treatment), 3) Spray-Irrigation and Field Spreading (Fig. 1).

The methane generator (Fig. 2 - Table 1) is basically an underground tank in which organic solids are digested by anaerobic bacteria. These bacteria metabolise the carbohydrates and proteins in the waste and liberate a mixture of gases (predominately methane - CH_4) as a waste product. The process of anaerobic digestion has been thoroughly discussed in the literature, and so will not be repeated here.[1-3] The main digestion parameters considered were: 1) Wastes composition and production, carbon/nitrogen ratio, total and volatile solids content, daily production; 2) Treatment processes - digestion temperature, retention time, size reduction mixing, septic characteristics; 3) Materials and construction of tank, gas storage, insulation, size reduction, mixing, and heating.

Agricultural waste and domestic garbage are placed into the prep tank by a manual opening; human wastes are flushed from a holding tank below the building, into the prep tank. A total day's waste would be allowed to enter the prep tank (agricultural and human waste, and domestic garbage). Each night the size reduction equipment would be run and the wastes inputted into the tank. Excess water in the flush water storage tank, would be run through the entire system to move all the wastes into the digestion tank. The prep tank

should be large enough to accomodate two days of waste (approximately 500 gallons), in case the system needed to be temporarily shut down.

After being reduced to about 1/2" in the prep tank the wastes would enter the primary digestion chamber, where it is held for 15 days at 95°F. Approximately 80-90% of the digestion occurs in this chamber.[1, 2, 3] Mixing occurs in the primary chamber by bubbling the gas from storage through the slurry. The tank was designed to have a larger diameter than height to maximize the surface area for the given volume of slurry--this was done to reduce the buildup of scum on the surface of the slurry, which can reduce gas output and sometimes even shut down the entire digestion process.[1, 2, 3]

Each day, as waste enters the primary chamber an equal volume of digested slurry enters the secondary chamber by way of a removable plastic pipe (at least 4" in diameter). The pipe would be equipped with a valve, so that flow from the primary chamber could be stopped, when it is necessary to drain the secondary chamber. The pipe's inlet faces opposite of where the new waste is entering, to prevent undigested waste from flowing into the secondary chamber. Newly added waste, being heavier, than the digested material will first sink to the bottom, and float to the top as it is digested.

Each day, as new waste enters, an equal amount of effluent from the secondary chamber would be removed. Periodically the solids occurring at the bottom of the secondary chamber will be allowed to flow out through the bottom drain. The head of effluent above it will force the sludge through the pipes and into the sewage lagoons.

The digestion chambers must remain free of oxygen, in order for the methane producing processes to occur. Suitable valves are required at all entry and exit points of wastes and effluents. The digestor could be con-

structed from a prefabricated concrete silo or from poured concrete. The bottom and sides would be insulated with 3" of styrofoam. The wall separating the two chambers will also be insulated. A moveable leakproof roof, which serves as a gas storage tank, could be made from a prefabricated galvanized steel silo, or from fiberglass. The roof would be counterbalanced so that only a very small pressure would be exerted on the gas (only 1-2 lbs/ft^2--enough to move the gas through the pipes). Sufficient storage would be needed to handle peak cooking and electrical generating demands (about 250 ft^3). The entire digestion unit would be covered with a geodosic dome or other insulated structure to minimize heat losses. The tabulated waste inflow is shown in Table 2.

The second component of the waste system is a series of aquaculture-agriculture ponds (sewage lagoons) (Table 3). The entire waste flow (organic and grey water) of the community for one year would be placed into one of the four ponds. Organic waste and water as effluent and sludge would come from the digestor; the remainder of the grey water (sinks and laundry--see Section IV) would enter the ponds directly (not digested). The ponds would follow a four year rotation: 1st year--filling, 2nd year--aquaculture, 3rd year--harvest and drain pond, plant cover crop, 4th year--intensive crop production. After harvesting the crop(s) the sludge would be excavated, and repeats the same cycle. A small scoop on the tractor would be used for excavation.

The organic wastes would be stabilized by being incorporated into an aquatic food chain system.[5, 6] The first phase of stabilization would be external digestion of the organic solids by bacteria, fungi, protozoa, algae, ciliates, rotifers, etc. The soluble organics, colloids, biomass and detritus

produced by the first phase would then be subject to internal digestion (consumption) by bacteria, fungi, protozoa, algae, daphnia, ciliates, rotifers, etc. The final phase would be predaceous consumption of the resulting materials by fish, insects, zooplankton, etc. Background investigations into this type of advanced biological treatment system, indicate that high levels of organic waste stabilization (suspended solids reduction) and effluent quality can be achieved.[5, 6]

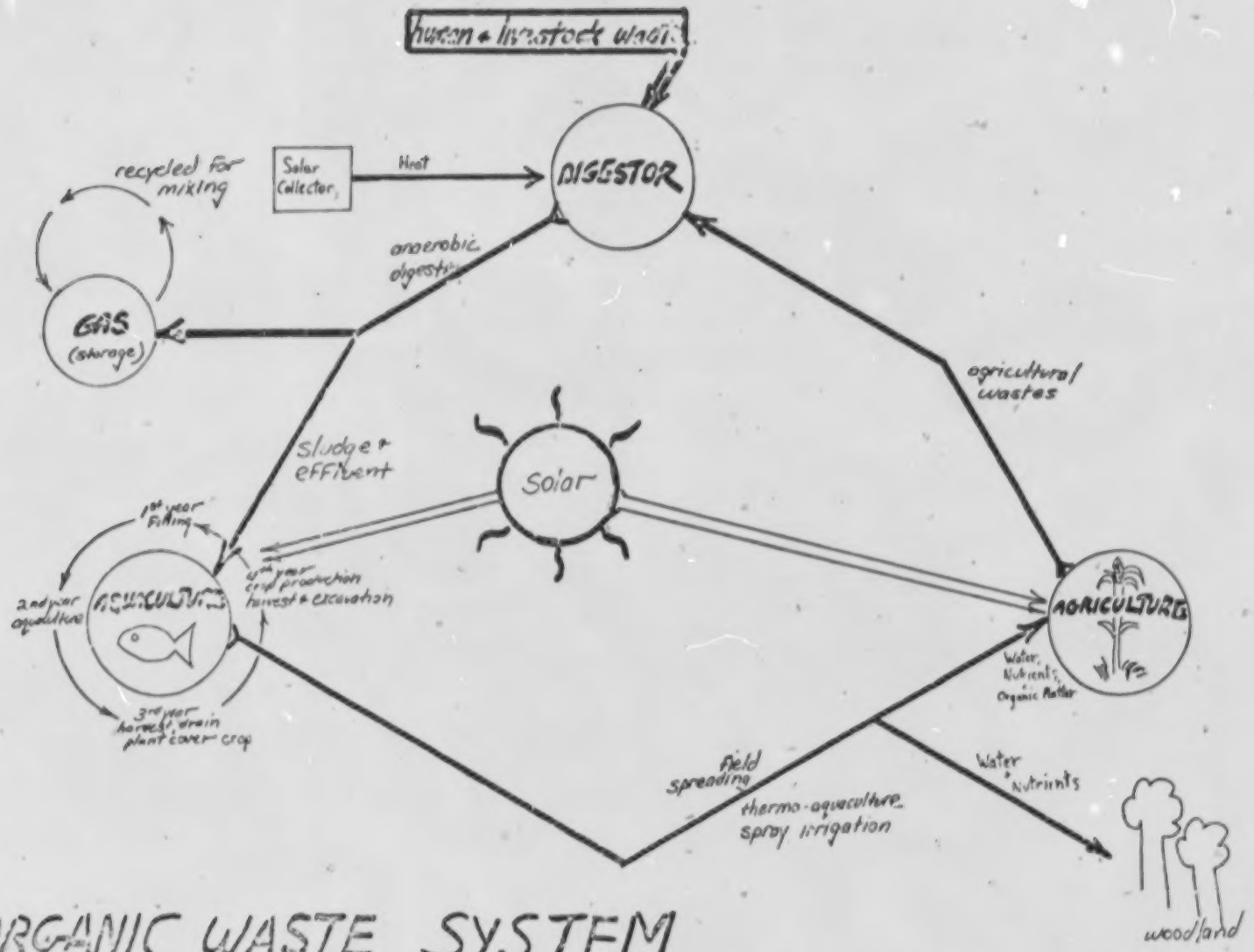
The ponds might be covered with a moveable greenhouse structure (to accomodate rotation); covered ponds would have an increased rate of biological activity (higher temperatures and longer growing season) and could be smaller because rainfall and runoff would not enter the pond. Harvested aquatic protein would be used for a high quality protein food source for poultry feeding.

The third component of the system is field spreading of the settled sludge and aquatic biomass, and spray irrigation of the effluent on crop and woodland. Incorporation of organic solids and soluble nutrients into the soil complex and/or growing crops would supply final stabilizing and treatment of the organic "wastes." Infiltration and percolation of the effluent would result in aquifer recharge, for supplying wells. Excess nutrients not taken up by vegetation would be either denitrified (nitrogen) by bacteria, fixed onto soil minerals (phosphorus), held onto soil colloids (potassium, magnesium and calcium), or incorporated into the soil biomass. Final septic treatment of the wastes would be achieved by soil microbial competition and antibiosis.

Preliminary calculations indicate that about 7000 lbs (3180 Kgms) of nitrogen, 2320 lbs (1050 Kgms) of phosphorus, and 2860 lbs (1300 Kgms) of

potassium would be flowing into the digestor/year (as elemental N, P, and K). Approximately 10% of the nitrogen would be lost in the generator (given off as ammonia) and of the remaining amount, 50% would be lost from the ponds (given off as volatile ammonia). None of the phosphorus would be lost in the generator; a 10% loss is the design estimate for these elements from the ponds. The amounts of nutrients that would be available for land application are: 3150 lbs (1430 Kgms) of nitrogen, 2090 lbs (950 Kgms) of phosphorus, and 2570 lbs (1170 Kgms) of potassium. If applied only on the agricultural land this would be a fertilization rate of: N = 204 Kgms/ha, P = 136 Kgms/ha, K = 167 Kgms/ha. This would be excessive for most cropping systems, so some would need to be applied to the woodland, or the cropping system increased.

Figure 1



ORGANIC WASTE SYSTEM

Figure 2

METHANE GENERATOR

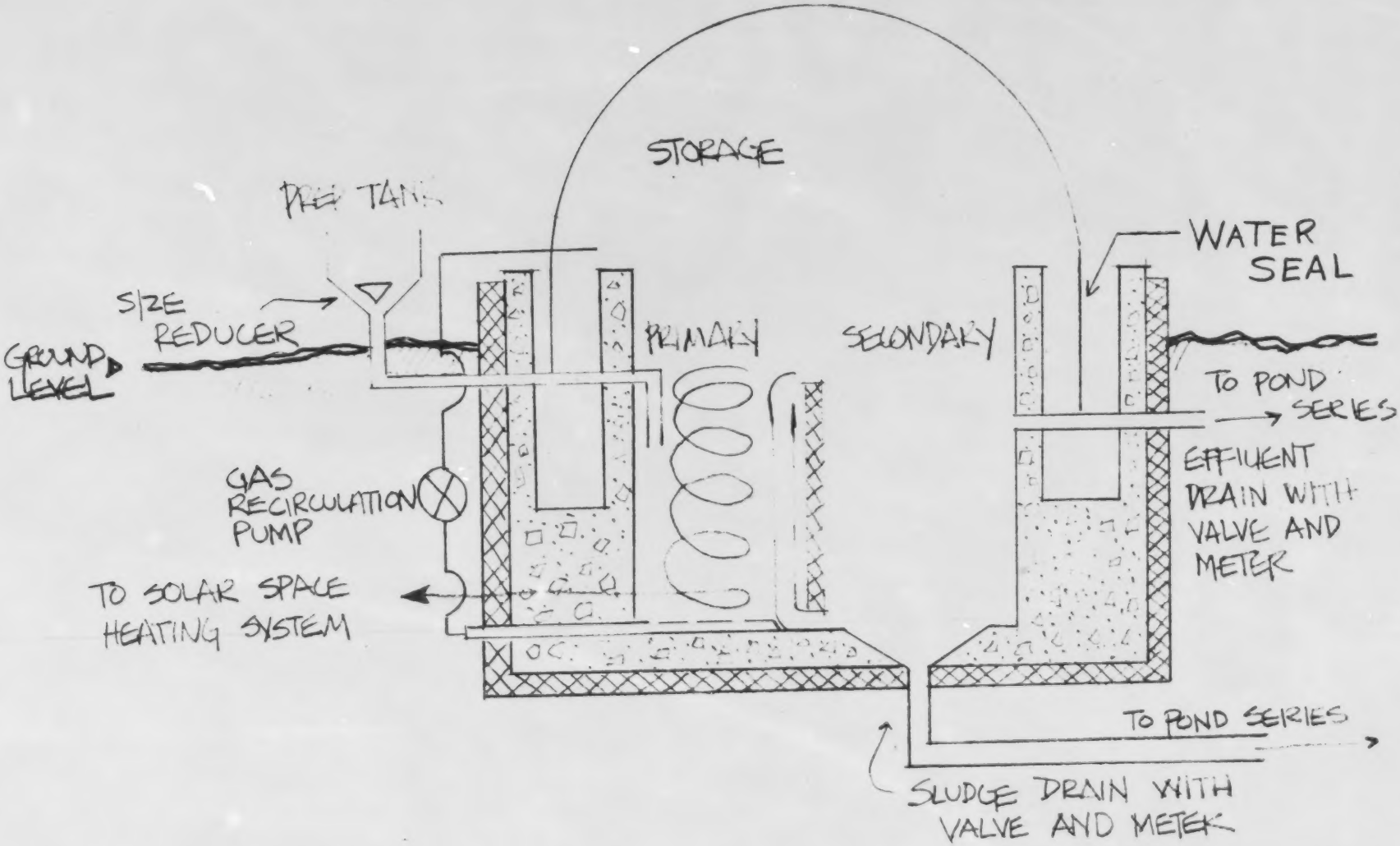


Table 1

Methane Generator (Anaerobic Digestor)

I. TANK SPECIFICATIONS

Diameter - 15' Height - 6' Total Capacity - 1,060 ft^3
Surface Areas - Sides - 282.6 ft^2
Bottom - 176.6 ft^2
Top - 200.0 ft^2 (allows for rising and falling top)
Materials - Tank Prefabricated concrete silo; Moveable Top - Fiberglass
Insulation - 3" Styrofoam insulation on all surfaces below ground.
Insulated geodesic dome shelter over entire digestor.
Digestion Parameters - 2-stage digestion; primary chamber maintained at 95° F;
-detention time: 30 days total
-Carbon/Nitrogen ratio:
-Solids Content: 7-9%
-Solids Reduction: 40%
-Mixing: recirculating of gas by pump

II. HEAT FLOW

A. Heat Loss: Therms/Month[a]

Sept. - 6.9	Dec. - 10.6	March - 11.0
Oct. - 8.6	Jan. - 11.2	April - 9.8
Nov. - 9.2	Feb. - 10.6	May - 9.2

Total/heating season - 86 Therms[b]

B. Heat Gains:

Bacterial Metabolism -

Wastes Inflow - Human waste 9.3 gals/day @ 90°F, Bathing Water 137.1 gals/day @ 90°, Dishwashing 56.4 gals/day @ 100°
Solar -

III. WASTE FLOW[c]

	Waste (lbs/day)	Total Solids (lbs/day)	Volatile Solids (lbs/day)	Nutrients N	P (lbs/day)	K
Winter	426.0	147.1	87.9	23.3	8.11	10.7
Summer	---	---	70.5	14.9	4.6	4.8
Total/year			28,945	7003	2319	2860

Table 1 (Continued)

IV. GAS PRODUCTION AND UTILIZATION

	Production/day	Production/month (30 days)	Production/year
Gas	560 ft^3 (2.8 Therms)	16,800 ft^3 (101 therms)	204,400 ft^3 (1226 Therms)
Electricity	17 Kwhrs (363 ft^3)	510 Kwhrs (10,890 ft^3)	6205 Kwhrs (132,495 ft^3
Cooking	197 ft^3 (1.2 Therms)	5910 ft^3 (35.5 therms)	71,905 ft^3 (431.4 Therms)
Waste Heat[c] (from internal combustion engine exhaust and cooling system)	.4 Therms	65 Therms	694 Therms

References

a) Calculated using the following:
Heat Loss Bottom = 1/2 area x ΔT (95° - 6' = Temp. @ 50°) x U(.1) = BTU/Hr
Heat Loss Side = 1/2 area x ΔT (95° - avg. monthly temp @ 36") x U(.1) = BTU/Hr
Heat Loss Top = 1/2 area x ΔT (95° - avg. monthly air temp.) x U(.05) = BTU/Hr
U values - Styrofoam + Concrete = .1
- Dome Shelter = .05
Area of heat loss is taken at 1/2 tank component's area, because only 1/2 of tank is being heated.

b) Only calculated for September-May because during summer there is no heat loss for building, so there will be excess heat from solar collectors.

c) Assuming 66% of energy input into engine is given off as waste heat (1/3 from exhaust, 1/3 from cooling system).

Table 2

Organic Wastes System - Materials Flow

Unit	No.	Waste (lbs/day)	Total Solids (lbs/day)	Volatile Solids (lbs/day)	Estimated Gas Production (ft^3/day)	Nutrients N (lbs/day)	Nutrients P (lbs/day)	Nutrients K (lbs/day)	H_2) to add/day (gals)	Total	Volume (ft^3)
Winter (185 Days)											
People	30	Feces: 15.0 Urine: 66.0	4.05 3.96	7.50	45.0	.90 11.02	.62 2.51	.27 2.51	4.8 0	14.5	1.93
Digestable Domestic Garbage (DDG)		30.0	16.50	15.00	150.0	.26	.25	.19	23.1	26.7	3.57
Milk Goats	8	100.0	25.00	17.60	88.0	4.00	1.40	2.90	28.4	40.4	5.41
Goat Kids	16	112.0	28.00	20.80	104.0	4.48	1.57	3.25	31.9	45.3	6.06
Chickens (Layers)	50	15.0	5.25	3.00	15.0	.82	.73	.38	6.7	8.5	1.14
Chickens (Broilers)	100	20.0	7.00	5.00	25.0	1.10	.97	.50	8.9	11.3	1.51
Bedding		58.0	49.30	14.50	101.5	.58	.04	.58	72.8	79.8	10.66
Hay		10.0	8.00	4.50	31.5	.16	.02	.16	12.5	13.7	1.84
Total/day		426.0	147.06	87.90	560.0	23.32	8.11	10.74	189.1	240.2	32.12
Total/season		78,810 lbs	27,206 lbs	16,262 lbs	103,600 ft^3	4314 lbs	1500 lbs	1987 lbs	34,984 gals	44,437 gals	5942 ft^3

Table 2 (Continued)

Organic Wastes System - Materials Flow (Continued)

Summer (180 Days)											
People	30	Feces: 15.0 Urine: 66.0	4.05 3.96	7.50	45.0	.90 11.02	.62 2.51	.27 2.51	4.8	14.5	1.93
Domestic Garbage		30.0	16.50	15.00	150.0	.26	.25	.19	23.1	26.7	3.57
Milk Goats	8	25.0	6.25	4.40	22.0	1.00	.35	.72	7.1	10.1	1.35
Goat Kids	16	28.0	7.00	5.20	26.0	1.12	.39	.81	8.0	11.3	1.51
Chickens (Layers)	50	3.8	1.31	.75	3.8	.21	.18	.09	1.7	2.1	.28
Chickens (Broilers)	100	5.0	1.75	1.25	6.2	.28	.24	.12	2.2	2.8	.38
Bedding		14.5	12.33	3.63	25.4	.15	.01	.14	18.2	19.4	2.67
Plant Wastes		196.0[a]	43.14	40.23	281.6	--	--	--	46.3[b]	69.8	9.33
Total/day		383.4	96.29	70.46	560.0	14.94	4.55	4.85	111.4	156.7	21.02
Total/season		69,012 lbs	17,332 lbs	12,683 lbs	100,800 ft^3	2689.2 lbs	819.0 lbs	873.0 lbs	20,052 gals	28,206 gals	3784 ft^3
Total/year		147,822 lbs	44,538 lbs	28,945 lbs	204,400 ft^3	7003 lbs	2319 lbs	2860 lbs	55,036 gals	72,643 gals	9726 ft^3

a) Approximate: total weight depends on moisture and volatile solids of waste.

b) At 78% moisture.

Table 3

Sewage Lagoons for
Pond Series (Organic Waste Stabilization)

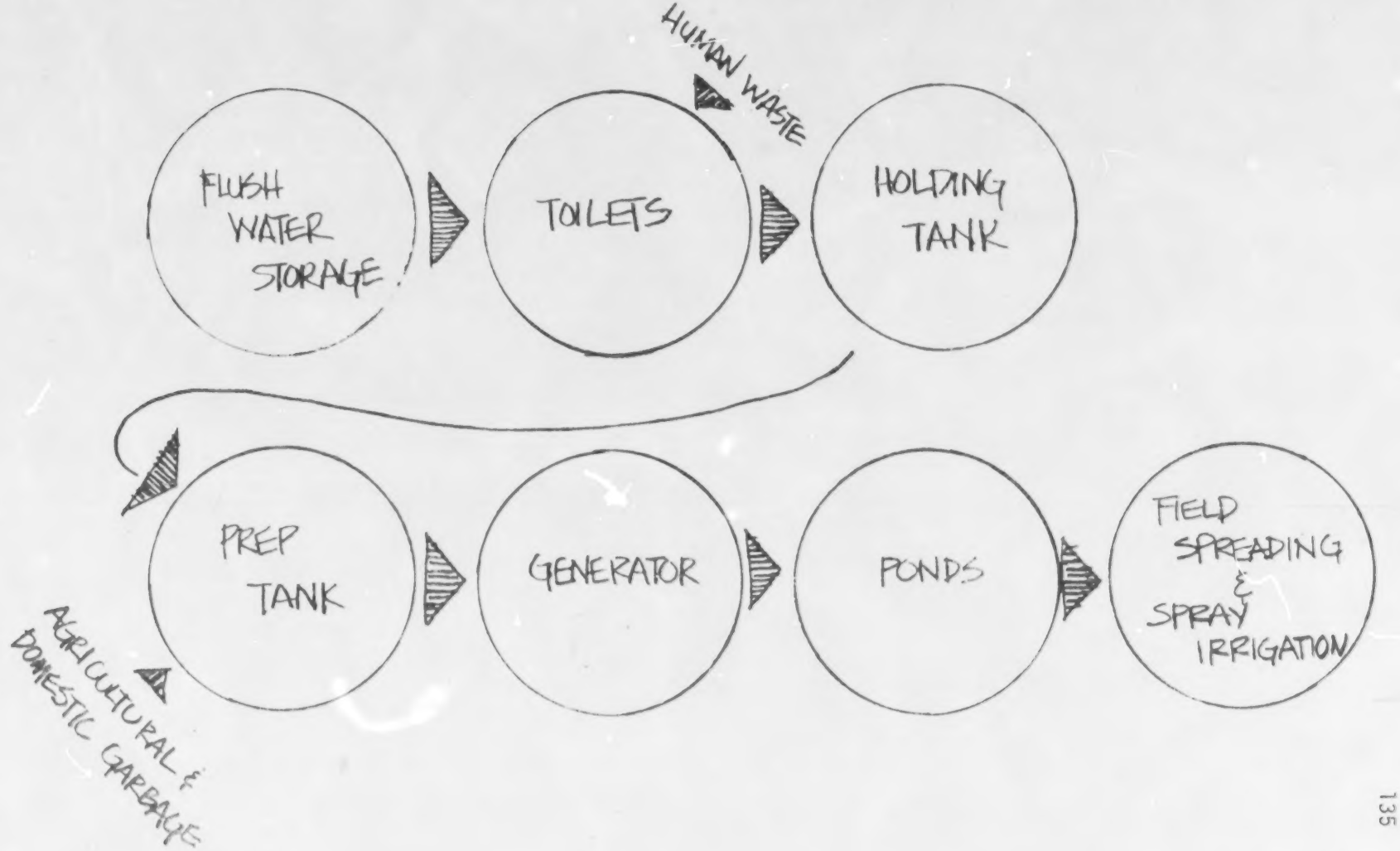
Year	Pond	Function
1	1	Filling, Build 2
2	1	Aquaculture
	2	Filling, Build 3
3	1	Harvest Fish and Plant Green Manure Crop
	2	Aquaculture
	3	Filling, Build 4
4	1	Intensive Veg. Production, Then Excavation
	2	Harvest Fish, and Plant Green Manure Crop
	3	Aquaculture
	4	Filling
5	1	Filling
	2	Intensive Veg. Production, Then Excavation
	3	Harvest Fish and Plant Green Manure Crop
	4	Aquaculture
6	1	Aquaculture
	2	Filling
	3	Intensive Veg. Production, Then Excavation
	4	Harvest Fish and Plant Green Manure Crop
7	1	Harvest Fish and Plant Green Manure Crop
	2	Aquaculture
	3	Filling
	4	Intensive Veg. Production, Then Excavation
8	1	Intensive Veg. Production, Then Excavation
	2	Harvest Fish and Plant Green Manure Crop
	3	Aquaculture
	4	Filling

Total Waste and Water Inflow/year = 14,940 ft^3

Pond Size Required - Uncovered -.34 Acre (ha). (In a 4.5 ft deep pond this allows 1' for the waste water and 3.5' for rain). Covered - .08 Acre (300 $meter^2$) (allows for 4.5 ft of waste water). 4 uncovered ponds - 1.4 Acres (.56 ha). 2 covered ponds - .32 Acres (1200 $meters^2$).

Figure 3

WASTE WATER FLOW CHART



II. CONCLUSIONS AND DISCUSSION

In our design we attempted to incorporate desirable features of many other systems.[1-8] The community's organic waste system has many advantages, but also many drawbacks and unresolved questions.

One main feature of the system, and a main reason anaerobic digestion was chosen, is its production of a useful fuel. This fuel source forms a major portion of the community's energy supply. But the estimated gas production in our design may be subject to fluctuation: various sources indicate different rates of gas production. Our estimates are an average from all the consulted references. There is also the danger of explosion in an enclosed atmosphere of 5-15% methane. Gas storage and piping systems would have to be carefully leak-proofed and any structure over the digestor adequately ventilated. Possibly some type of monitoring device could evaluate the composition of the air inside the digestor's shelter and operate ventilation accordingly. Extreme fluctuations in gas production (due to varying) would severely impair the community's operation. Without the use of agricultural wastes, gas production would not be adequate for meeting the present design requirements. The actual heat flow of the generator may be much different than those calculated. Maintaining proper temperatures could be an energy expensive process. There may be the danger of overheat in summer. Only materials which would not be harmful to the anaerobic bacteria could be flushed into the system. Odors from the digestor or prep tank may be a problem. The capital and operating costs of the digestor is still unknown, but these costs would be balanced against three types of benefits: waste treatment, nutrients, and energy production.

The system's general tolerance to fluctuations needs to be determined. Any variation, such as changing water of waste inputs, toxic substances, scum buildup, bacterial dieoffs, etc., which would shut down the system might seriously affect the community's operation and safety. Some type of back up systems would be necessary (gasoline for the engine, outhouses, etc.).

An extremely important consideration is the system's effectiveness in reducing health hazards from human pathogens. Preliminary background investigations[5, 6, 7] indicate that these would not be a problem due to the many different biologic treatment processes utilized (digestion @ 95° for 30 days + a 4-year aquatic-terrestrial rotation system in the lagoons, and field application) and the time span involved. In addition sludge and effluent applications might be restricted to woodland and the non-food crops in the system's rotations. Sludge may be aerobically composted, before utilizing on food crops to destroy pathogens. As a final precaution the effluent and sludge could be disinfected with chlorine or ozone gas as it leaves the digestor.

In general, the system's major dependence on biological processes, bacteria, aquatic organisms, soil micro flora and fauna, appears to be a reasonable and necessary trend in organic wastes system. Organisms and ecosystems can carry out complex processes while utilizing local resources (solar radiation and organic materials). The "machinery" which carries out these processes i.e. organisms and ecosystems, is self replicating and maintaining. Also the "self-design" capacities of biological systems allows them to adapt to fluctuating environmental conditions. Many of our background studies indicate the advanced biological treatment and resource recovery (agriculture and aquaculture) will be the only economically and ecologically reasonable strategy in the future.[5, 6, 7] At present the data available for such systems is small, but possibilities seem quite unlimited.

The only to evaluate the actual operation and economics of such systems would be to construct small prototypes of particular components or complete waste recovery systems. Monitoring all inputs, outputs and behaviors of such systems would provide useful data on which new designs and cost/benefit analysis could be based.

Many other systems could have been incorporated into such a waste treatment system which could increase the overall efficiency, stability and productivity of the system. Algae grown in effluent in greenhouse conditions could be used for animal food and/or recirculated into the digestor for conversion into gas, aquatic and marsh type plants (cattails, water hyacinth) grown in effluent ponds for food, feed and fiber, utilizing the effluent for hydroponic cultivation, cultivating earthworms on digestor sludge and plant wastes for high quality protein animal food, a separate solar system for heating the digestor, some means of converting the gas into a liquid fuel (methanol) for longer and more convenient storage, and development of fuel colls which could convert hydrocarbon gases directly into electricity. Similar investigation is needed for ways of handling other solid wastes the community will produce. The entire system could be a valuable research and learning tool. Studies in microbial and lagoon ecology, sanitary engineering, soil fertility, etc. could all be carried out with such a system.

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Appendix I

Waste Production and Composition

Material	Composition Total Solids %	Composition Volatile Solids %	N (%)	P (%)	K (%)	Estimated Gas Production (ft^3/lb Volatile Solids)	Daily Production
Human Waste							
Feces	27.0	9.3	6.0	4.2	1.8	6	2.2 lbs/person
Urine	6.0		17.0	3.8	3.8		.5 lbs/person
Digestable							
Domestic Garbage (DDG)	55.0	50.0	.9	.8	.6	10	1.0 lbs/person
Manure							
Milk Goats	25.0	17.6	4.0	1.4	2.9	5	12.5 lbs/goat
Goat Kids	25.0	18.6	4.0	1.4	2.9	5	7.0 lbs/kid
Layers	35.0	20.0	5.5	4.8	2.5	5	.3 lbs/bird
Broilers	35.0	25.0	5.5	4.8	2.5	5	.2 lbs/bird
Plant Material							
Bedding	85.0	25.0	1.0	$\frac{.0007 \text{ lbs}}{\text{lb straw}}$	1.0	7	7.25 lbs/goat/day
Hay	85.0	45.0	1.6	.2	1.6	7	
Grass	22.0	20.5				7	

a) Information and data derived from references 1-9.

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SECTION IV - DOMESTIC ENERGY AND WATER USE

I. INVESTIGATIONS

The objectives of this working group were: 1) investigate ways to minimize domestic energy and water consumption; 2) investigate the factors influencing consumption; 3) to quantify the power and water requirements for the community; 4) to investigate the feasibility of local, renewable sources of energy production, i.e. windpower, solar, and methane gas production from organic wastes.

Domestic energy and water consumption is determined by several factors: number, types, usage rate, and efficiency of household equipment and processes i.e., freezing, refrigeration, cooking, lighting, cleaning and bathing, communications, and amenity appliances. Lifestyle choice affects all of these factors, e.g. amount of frozen food eaten, size and utilization of refrigerated space, food choices and preparation methods, space requirement, intensity, and utilization of lighted areas, amount of cleaning and bathing desired, number of amenity appliances desired, organization and size of the social unit utilizing the energy requiring processes, and in general, the amount of time people are willing and able to devote to domestic activities, and the type of household environment they desire.

The approach of this working group was to investigate this influence of lifestyle on energy consumption and then roughly "design" a lifestyle which would minimize energy consumption.

In order to quantify energy and water consumption a design for a domestic service system for thirty people was developed. First, the service systems which seemed most basic and essential to a high quality standard of living were determined; refrigeration, freezing, gas or electric

cooking, lighting, space heating, indoor, running hot and cold water, and communication. The capacities needed and usage rates for thirty people were determined; then the requirements for the processes and machinery were calculated. (Tables 1-A, B, C and 2). Tables 1-A, B and C clearly illustrate the effect of lifestyle choice on electrical energy consumption. By changing the number, types and usage rates of various appliances, and therefore the type of domestic lifestyle, fluctuating electrical requirements were generated.

From our background investigations[20] it appears that a cooperative living unit could minimize resource use, and capital requirements. Resource requiring processes are to be centralized to obtain an "economy of scale" in operation and utilization, and to reduce duplication of machinery involved.

A comparison was made between a cooperative kitchen for thirty people and six individual kitchens serving five people each. Table 3 illustrates the lower cost of a group kitchen in electrical requirements and capital outlay. Energy requirements (gas) for cooking and labor requirements (per person) for food preparation and kitchen maintenance may be lower in the cooperative kitchen, because duplication of kitchen activities could be reduced and efficiency of labor increased, by preparing foods in quantity (e.g. one person can monitor a 20 qt. pot as easily as a 4 qt. pot). Also daily labor requirements per person could be reduced by rotating the work load (e.g. a three person team could easily handle the entire food processes for a set time, leaving the remaining community members free from kitchen chores for that time).

Table 1-A

Minimum Electrical Requirements

	Kilowatt-Hours/ month/30 people
FOOD PROCESSES	
REFRIGERATION - 21.9 ft^3 Average Draw 500 Watts[1], [2], [20] 70° Ambient Temp. 365 hr/month Hobart Model Cost $499.00	146.0
FREEZER - 25 ft^3 Chest-Type Runs 55% of the Time[21], [3], [4] 70° Ambient Temp. 402 hr/month 230 Watts	92.5
LIGHTING	
UTILITY LIGHTING - Fluorescent 600 Watts - 90 hr/month Kitchen, Bathroom, Study and Recreational Areas	54.0
INDIVIDUAL LIGHTING - Fluorescent 50 Watts/day/person Rooms, Hallway, and Clocks 3 hr/day	150.0
LAUNDRY	
WASHING MACHINES (2) - 275 Watts Each[5] Wringer Type 20 hr/month/each	11.0
IRON - 1008 Watts 6 hr/month[6]	6.0
ENTERTAINMENT	
TELEVISION - B+W/Solid State 90 hr/month 237 Watts[1], [5]	21.0
RADIO - Solid State Model 90 hr/month 25 Watts[3], [7], [9]	2.25
STEREO - 100 Watts Input 90 hr/month	9.0
MISCELLANEOUS	
HAIRDRYER, SHAVER, ETC.	3.0
Total Electrical Consumption/month	492.0
Daily Electrical Consumption	16.4

Table 1-B

Mean Electrical Requirements

ENTERTAINMENT	Kilowatt Hours/ month/30 people
TELEVISION - B+W, Solid State Model, 120 hr/month, 237 Watts[5]	28.4
RADIO - Solid State Model, 25 Watts, 120 hr/month[7], [3]	3.0
STEREO - 100 Watts Input, 120 hr/month	12.0
LAUNDRY	
WASHING MACHINE - 275 Watts each (2) @ 20 hr/month each[5]	11.0
IRON - 1008 Watts, 6 hr/month[12]	6.0
LIGHTING	
UTILITY LIGHTING - Fluorescent, 600 Watts, 120 hr/month	72.0
LIGHTING & CLOCKS - Fluorescent, 50 Watts/person/day, 4 hr/day	200.0
FOOD	
REFRIGERATOR - 21.9 ft^3, 70° Ambient Temp.[1], [2] 50 Watt Draw - Avg.. 365 hr/month	146.0
FREEZER - Chest Type, 25.3 ft^3 at 70° Ambient Temp.[3], [4] 13 hr, 12 min/day, 402 hr/month, 230 Watts	92.5
DISHWASHER - Electric, 1200 Watts, used once/day[8]	36.0
MISCELLANEOUS	
HAIR DRYER, SHAVERS, ETC.[9]	4.0
Total Electrical Consumption/month/30 people	611.0
Daily Electrical Consumption	20.4

Table 1-C

Maximum Electrical Requirements

	Kilowatt-Hours/ month/30 people
ENTERTAINMENT	
TELEVISION - B+W, Solid State Model, 237 Watts, 150 hr/month[5]	35.5
RADIO - Solid State Type, 25 Watts, 150 hr/month[7], [3]	3.75
STEREO - 100 Watts Input, 150 hr/month	15.0
LAUNDRY	
WASHING MACHINES - (2) (automatic) 500 Watts each, each used 20 hr/month[3]	20.0
CLOTHES DRYER - Electric, 4856 Watts, Used 18 hr/month[5]	86.0
IRON - 1008 Watts, 8 hr/month	8.1
LIGHTING	
UTILITY LIGHTING - Fluorescent, 600 Watts, 150 hr/month, 6 hr/day	90.0
LIGHTING AND CLOCKS - (Fluorescent), 5 hr/day/person, 50 Watts/day/person	250.0
FOOD	
REFRIGERATION - Commercial Unit, 70° Ambient Temp.[2], [1] 47.2 ft^3, 365 hr/month, 600 Watts	219.0
FREEZER - 25.3 ft^3, 70° Ambient Temp., 402 hr/month, 230 Watts[3], [4]	92.5
DISHWASHER - Electric, 1200 Watts, used twice/day[8]	72.0
MISCELLANEOUS	
HAIRDRYER, SHAVER, FLOOR POLISHER[9]	5 Kwhr/Month
Total Electrical Consumption/month	897.0
Daily Electrical Consumption	29.9

TABLE 2

Water Requirements

I. Function	Gals/Day/Person[21] (average)	Gals/Day/Person[21] (reduced)
Cooking & Drinking	3.75	1.88
Dishwashing	3.00	2.00
Laundry	8.75	2.86
Bathing	20.00	4.57
Sink	2.00	.70
Toilet	25.00	2.50
Total	62.50 gals/day	12.01 gals/day
Total/30 people	1875.00 gals/day	360.30 gals/day

II. Water Saving Devices[21]	Reduction
Faucet Aerator	25%
Flow Control-faucets	40%
Valves -showers	60%
Spray Tap	50%
Wringer Washer	33%
Cooking Methods (pressure cooker, wok)	33%

III. Reduced Water Needs

Function:	Dishwashing	Laundry	Cooking & Drinking	Bathing	Sink	Toilet
Treatment:	Spray Tap	Wringer Washer 1 wash/wk /person	Improved Cooking Methods	Flow Control Valve Reduced use 4 showers/ week/person	Aerator Flow Control Valve	1 qt flush + recycled flush water
Effect:	50% Reduction	20 gal/ person/ week	33% Reduction	77% Reduction	65% Reduction	100% Reduction

Figure 1

Water Flow - Gals/day/30 people

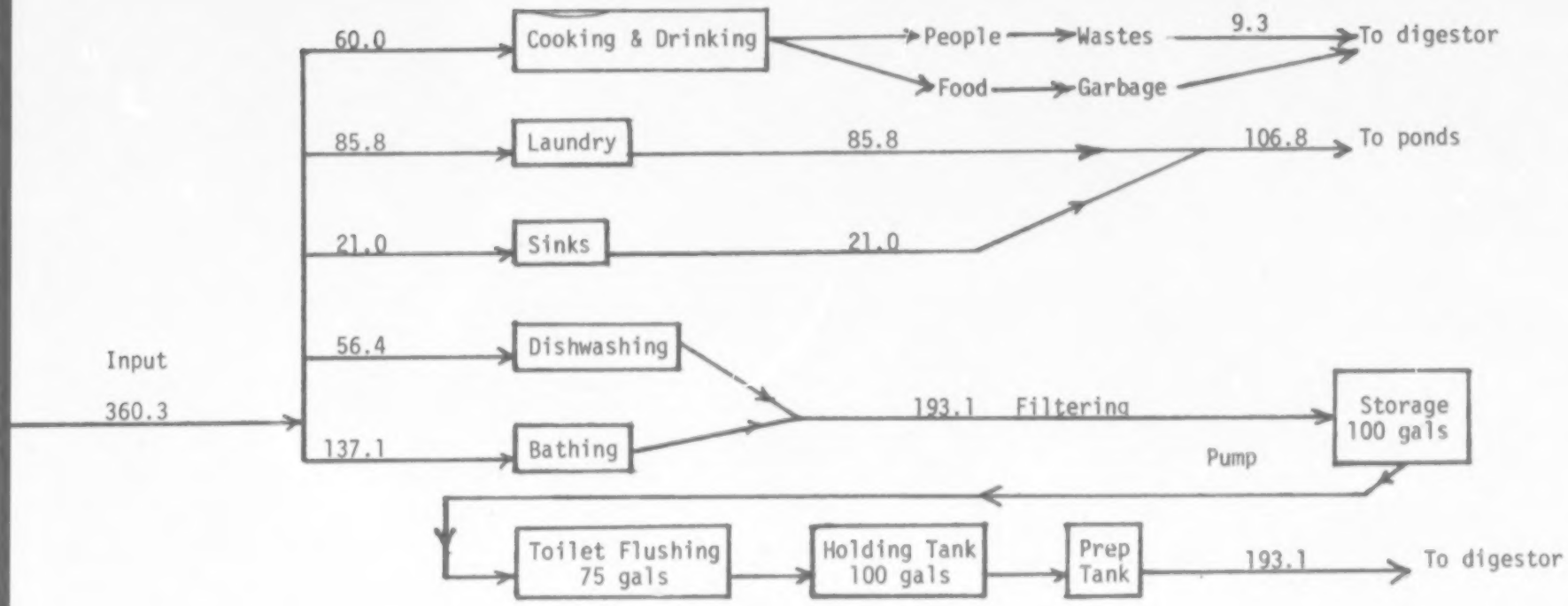


Table 3

Comparison Between a Cooperative Kitchen Facility for

30 People and Six Family Kitchens for 5 People Each

	Cooperative Kitchen	Family Kitchen (6)
Gas Range and Oven - Description:	"Vulcan"[2] Six burners @ 15,000 BTU/each; Oven burner @ 35,000 BTU[2]	Typical home gas range and oven[10,3] @ $200.00 each
Cost:	$468.00	6 @ $1,200.00
Refrigeration - Description(s):	Refrigerator: Hobart Commercial Refrigerator[3] 21.9 ft^3 @ 146 Kwhr/ month; Cost: $1,194.00 Freezer: Chest-type[3,4] 25.3 ft^3 @ 92.5 Kwhr/ month; @ 499.00	Combination Refrigerator Freezer[3], not frost-free @ $309.00 each; @ 110 Kwhr/month each
Cost:	$1,693.00	6 @ $1,854.00
Electrical Consumption:	238.5 Kwhrs/month	660 Kwhrs/month
Dishwasher - Description:	Hobart Commercial[2,8] @ $700.00; @ 36 Kwhr/ month	"Norge" Built In[3,5,11] @ $269; @ 20 Kwhr/ month
Cost:	$700.00	6 @ $1,614.00
Electrical Consumption:	36 Kwhr/month	6 @ 120/month
Miscellaneous Kitchen Equipment -		
Cost:	$400.00[10]	@ $200.00 each[10] Total $1,200.00
Total Cost	$3,282.00	$5,868.00
Total Electrical Consumption	274.5 Kwhrs/month	780 Kwhrs/month

After determining approximate domestic energy requirements, ways of meeting these requirements were investigated. Since one of our project's goals was to supply the energy requirements from local renewable energy sources, these sources were given the most investigation. Also available for meeting the community's energy needs are commercial electricity, fuel oil, coal, and other fuels. Energy sources evaluated were solar energy (flat plate collectors) with wood as a back up heat source for the space and hot water heating, methane gas from organic wastes for cooking, absorbtion refrigeration, and for generating electricity by use of an internal combustion engine, wind power for intermittent pumping and electrical needs of entertainment appliances, commercial electricity for continuous and heavy electrical loads, and fossil fuels for back up systems.

The problem, then, has been determining and evaluating an optimal arrangement and utilization scheme for our local and commercial energy sources to meet the community's energy needs and design goals, i.e. minimized use of fossil fuels, minimal capital outlay, and dependable and efficient operation.

Electricity Supply

One potential method of generating electricity is the use of wind power. The economy of windpower is a function of cost of harnessing it, which depends on the initial and maintenance costs of the wind-driven generator and storage system to be selected. The energy it can generate will vary depending on site characteristics, the efficiency of the generator used, and the loading schedule adopted.[12]

Local conditions effect the available wind power potential greatly. Therefore production estimates should not be based too heavily on statistics

of nearby areas, but instead on local site measurements of the proposed wind generating installation. Information on wind survey methods for short, medium, and long-period measurements is available.[13]

Local meterological data, from the State College and Phillipsburg weather stations, was used to understand the general, local wind behavior. Wind Roses (Appendix I) compiled at the State College Weather Station indicated the prevailing wind direction to be from the southwest.[14] Wind observations were analyzed on a daily basis for a five-year period. The prevailing wind was taken as a wind which blew for eight hours or more for any day. State College yearly wind velocity averages approximately 10 mph. The available wind data relates, however, to the general wind regime for the area surrounding the observation station, and not to a particular site which may have higher winds (open valley). The precise methods used in making the wind measurements at the State College station, including the type of instruments, methods of taking the readings, and the height above the ground was not available. This is an important factor to be considered in evaluating wind data. Table 4 is included to give an estimate of outputs from different size windplants at various average wind speeds.

The local wind regime is only one variable in setting up a wind power plant. Other factors require consideration before a system can be fully evaluated: characteristics and cost of equipment, access to the site, distance from electric service lines and possible centers of consumption, power requirements in the area, and characteristics of the terrain.

A preliminary investigation was made of some possible systems to meet the community's electrical demands. The largest wind generator currently in production in the world, has a monthly output of 325 kwhr in 10 mph

Table 4

Wind Generating Potential

Nominal Output Rating of Generator in Watts	AVERAGE MONTHLY WIND SPEED IN MPH				
	6	8	10	12	14
50	1.5	3	5	7	9
100	3	5	8	11	13
250	6	12	18	24	29
500	12	24	35	46	55
1000	22	45	65	86	104
2000	40	80	120	160	200
4000	75	150	230	310	390
6000	115	230	350	470	590
8000	150	300	450	600	750
10,000	185	370	550	730	910
12,000	215	430	650	870	1090

Source[5]

average winds. This would still not be sufficient to meet the total minimum energy requirements of 492 kwhr/month. A slightly smaller wind generating unit (Electro Model WVG50G--5000 wat,, 115 Volt DC/2000 watt, 115 Volt AC system) could provide 300 kwhr of power per month, under State College conditions (10 mph average). Coupled with a large electronic inverter, this could be used to supply all electricity requiring (287 kwhr/month) processes except refrigeration and freezing. Battery storage is sufficient for 3 windless days. The cost of the complete solar wind electric system was figured by dividing the total cost of the equipment over a 15 year period and then dividing by the number of Kilowatt-hours that the system could be expected to produce during that period of time. After the initial capital cost of the installation, there are no further costs other than maintenance which runs less than 1% of the original cost price per year.[15] For this system, the actual cost of wind generated power, calculated in this manner, is 17.7 cents per Kilowatt hour (the current residential rate in State College is 3.4 cents per kilowatt hour).[16] This analysis appears in Appendix 2. Another alternative is that the community could build its own wind generating unit(s). This would bring down the costs of the components substantially by using recycled components (e.g. automotive alternators). It would also result in an educational experience by students building the systems themselves. Plans are available for a homebuilt unit constructed by Jim Sencenbaugh[17] for about $400. "The unit will produce 400 watts of 110-volt AC power continuously or 500 watts intermittently at 80-85% efficiency."[18] This could provide enough alternating current to operate the stereo, radio and television. By constructing several home-built units energy requirements for laundry, partial lighting and miscellaneous requirements might also

be met. The remaining energy requirements could be met by the methane powered electric generator. A more detailed study into wind power was not made because of lack of time, the apparent poor economics of wind generated electricity in this area, the availability of electricity from the methane powered generating system (510 Kwhrs/month).

Hot Water Supply

The hot water system (Fig. 2) is basically a typical hot water tank with two additional heat exchangers. The two exchangers are connected to the cooling and exhaust systems of the internal combustion engine-electrical generator, which is fueled by methane gas from the anaerobic digestion system (see section III). The waste heat available from the engine provides the majority of the energy requirements for hot water heating. The balance of the requirements will be supplied by an auxillary fuel source (gas, oil, wood, coal). The relief valve on the tank will protect the tank from excessive temperatures. A solenoid in the tank will control the additional fuel requirements when the water temperature is too low. A solenoid on the engines cooling system will control coolent circulation to prevent over or undercooling of the engine. Table 5 summarizes the hot water and hot water system requirements.

Table 5

I. HOT WATER REQUIREMENTS

Function	Gals Required/day	Required Temperature
Dishwashing	56	120°
Laundry	86	100°
Bathing	137	110°
Sinks	21	110°
Total	300	
Total Gals/day @ 140°	216	
Total Gals/month @ 140°	6480	

II. ENERGY REQUIREMENTS AND SUPPLY

A. Heating water from 50° - 140°

(6480 gal/month) $(\frac{1\ BTU}{lb/°F})$ $(\frac{.1337\ ft^3}{Gal})$ $(\frac{62.4\ lbs}{ft^2})$ (140-60) = 43 Therms/month

@ 10% losses for tank base energy requirement for heating water = 54 Therms/month.

B. Waste Heat Available from Internal Combustion Engine

Total Waste Heat = 65 Therms/month

@ 80% recovery = 52.3 Therms/month useable

C. Tank Size

216 Gal/day demand

Probable maximum demand/hr = .25 x 216 = 54 gal/hr

Will utilize a 60 gal. hot water tank (water temp. permitted to drop to minimum of 120°).

D. Maximum Water Heating Energy Demand

$(\frac{60\ gal}{Hr})$ $(\frac{1\ BTU}{lb-°F})$ $(\frac{.1337\ ft^3}{Gal})$ $(\frac{62.4\ lb}{ft^3})$ (120-60)/.8 = 37,500 BTU/hr

(assuming .8 thermal efficiency)

E. Recovery Rate - available waste heat/hr for water heating

$(\frac{52.3\ Therms}{month})(\frac{10^5\ BTU}{Therm})(\frac{month}{720\ hrs})$ = 7,260 BTU/hr available (at a constant rate of electrical generation)

Heating Capacity - $\frac{7,260\ BTUhr \times 2}{(120-60)(62.4)(.1337)}$ = 29 gals/hr from 60°-120°F

(assuming that time of peak hot water demand coincides with a peak electrical demand - electrical generation would be at least 2x base load i.e. 1.4 Kilowatts/hr instead of .7 Kilowatts/hr (17 Kwhrs/day).

F. Actual Energy Requirements

During a day's use, it is assumed that 2 major peaks of hot water use will occur.

Maximum demand/hr - available waste heat/hr = amount of supplemental heat required/peak load

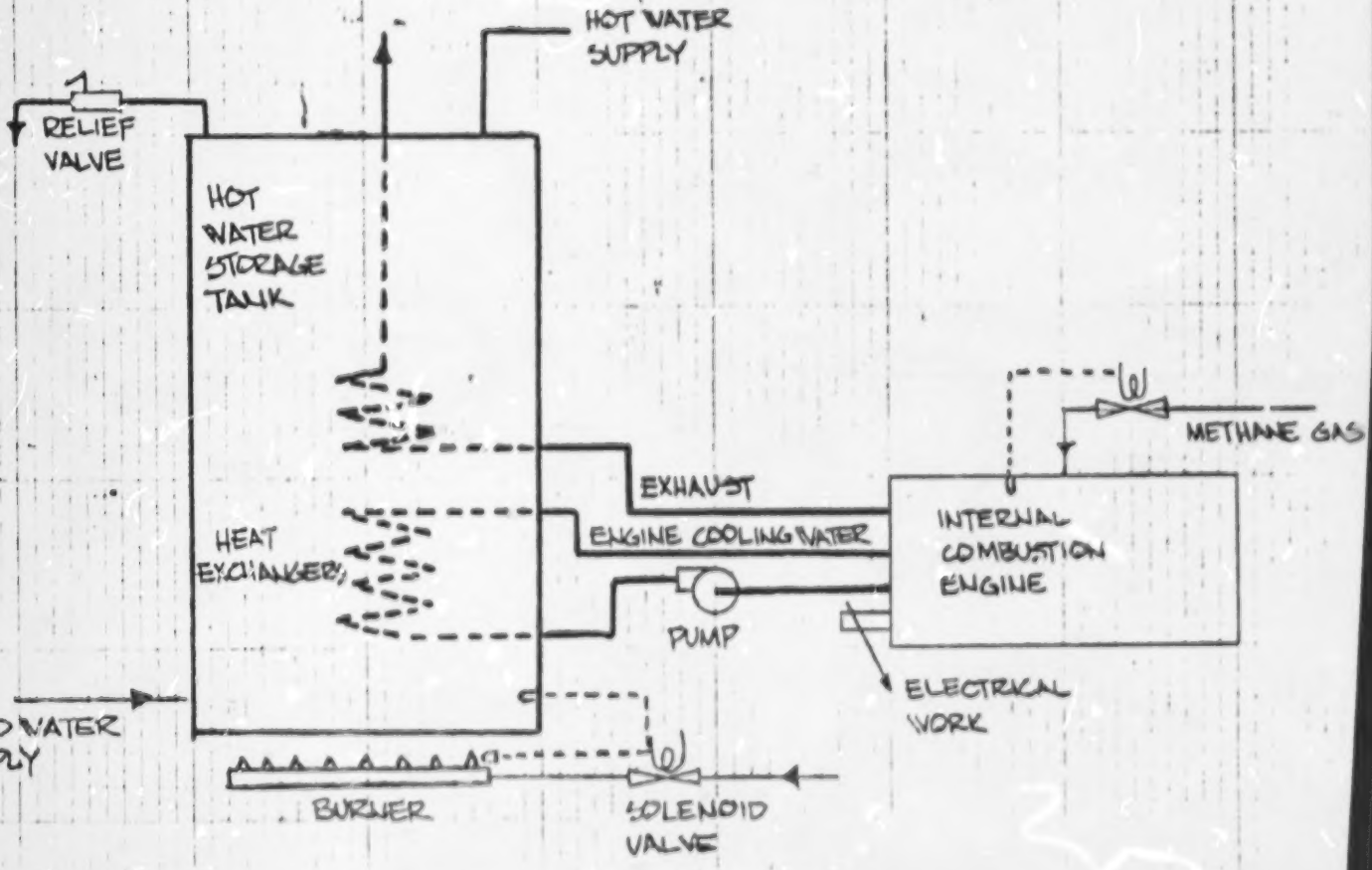
2 [37,500 - (7,260 x 2)] = 45,960 BTU/day supplemental heat required

124 Therms/heating season = 13.8 Therms/month

166 Therms/year

Figure 2

HOT WATER SUPPLY SYSTEM



III. CONCLUSIONS

The objective of minimizing energy and water requirements has been met only in theory. Members of the community would need to work cooperatively towards this objective at all times.

It appears that a cooperative kitchen could minimize energy, capital, and possibly labor requirements. Additional analysis is needed to more accurately evaluate energy, material, and labor requirements of domestic services, e.g. shelter, food preparation, cleaning, maintenance, etc., and possible reductions (per capita) of these requirements by utilizing cooperative efforts. The need to minimize resource consumption by using cooperative living must be balanced with the needs of personal privacy, flexibility and freedom.

The living/working environment of the community would provide a unique opportunity for making its members highly aware of the resources required in everyday living and for developing new habits to minimize these requirements. The cooperative living situation could be viewed as a continuous on-going experiment. The investigators would become a part of the system being investigated. Energy and water use could be monitored to evaluate effects on consumption patterns due to changes in useage schedules (time and frequency of showering, clothes washing, etc.), organization of domestic activities e.g. cooperative vs. individual cooking, and adoption of new technologies and hardware (new cooking equipment, shower heads, toilets, etc.).

There are many other available methods and devices for reducing energy and water use (see references and bibliography). Adequate time and/or information was not available to investigate all of these (also they are published elsewhere). One strategy, which is very applicable to a learning-research

confer situation, would be the construction and evaluation of prototype energy and water technologies by the community's members.[18, 19] This would result in lower costs for experimental (non-mass produced) equipment, accurate in-use evaluations, and a valuable addition to the center's education and research programs. The availability of an adequate size gas absorbtion refrigerator would have reduced electrical requirements and increased the efficiency of methane gas utilization (direct burning at refrigerator would result in less losses due to transforming gas into electricity). The availability of fuel cells which transform hydrocarbon gases directly into electricity might be useful in developing a highly efficient method of utilizing limited supplies of on-site generated gas.

A more practical solution to the community's energy requirements might be: utilization of commercially available electricity and direct burning of methane gas for the space and hot water heating requirements (in conjunction with either the solar or wood heat systems). This would result in 1) reduced capital expenditures for both solar and wood heat systems, 2) more efficient utilization of gas, 3) greater flexibility in the community's operation to allow for experimentation, power tools, etc. Major applications of wind generated electricity for this area with available machinery is not economically feasible. On-site wind measurements are necessary to make an accurate estimate of wind power possibilities. Wind might be a feasible energy supply for certain variable load requirements (e.g. pumping systems for fish ponds).

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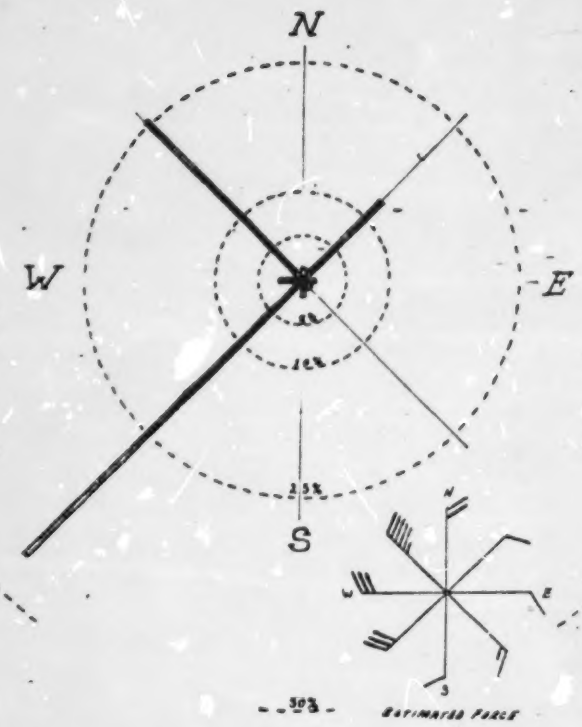
APPENDIX 1

The following wind roses were drawn from data recorded on a Triple Wind Recorder at the Pennsylvania State College Weather Station from January 1945 to December 1949. They indicate the frequency of the prevailing wind, or the percentage of the total number of observations that the wind was blowing from one of the eight directions. Analyzed on a daily basis, the prevailing wind was taken as a wind which blew for eight hours or more for any day. The red lines on the roses indicate the direction from which the wind is blowing. Percentage frequency is indicated by the dashed lines.

Wind forces are indicated by barbs at the ends of the lines on the small graph at the bottom of each page. The arrows fly with the wind and each barb indicates 5 m.p.h. These wind forces are estimated and are included only to show relative force.

JANUARY



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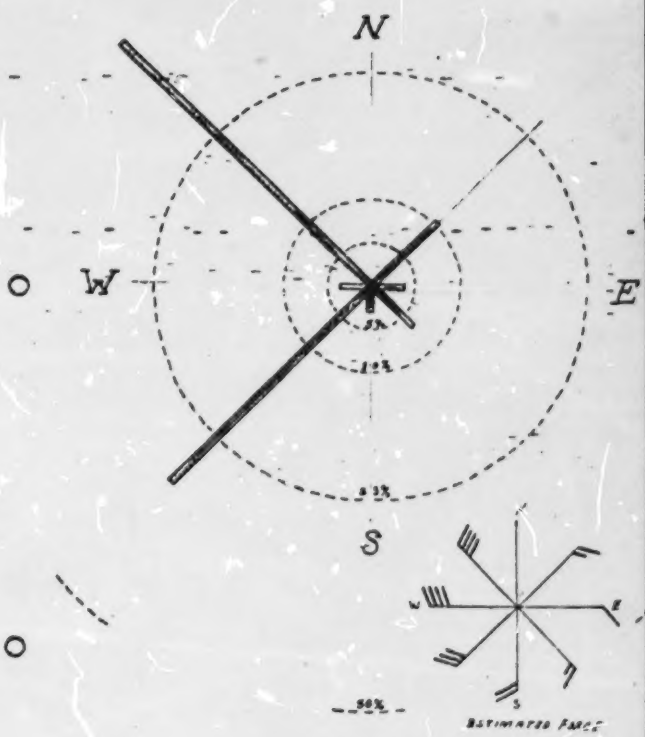

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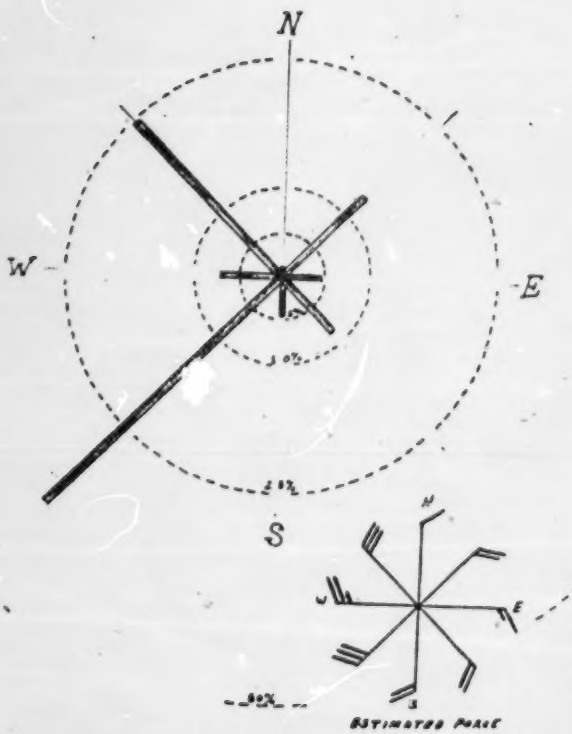

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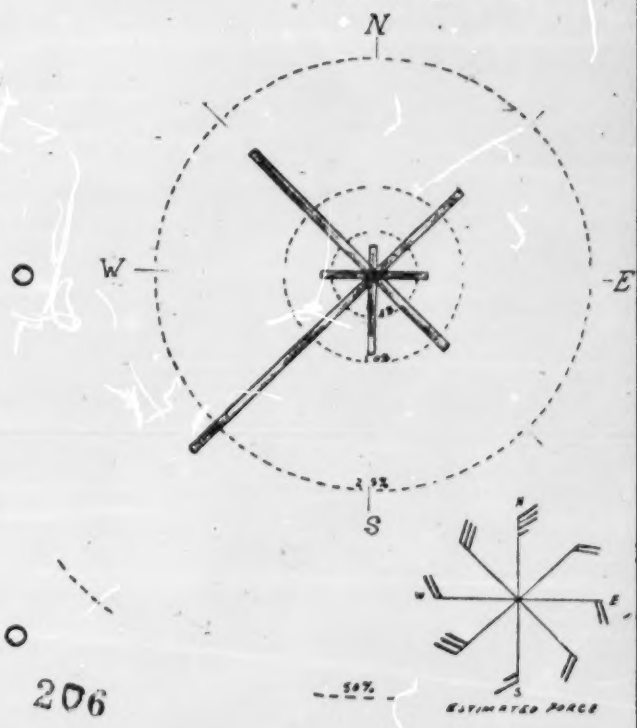

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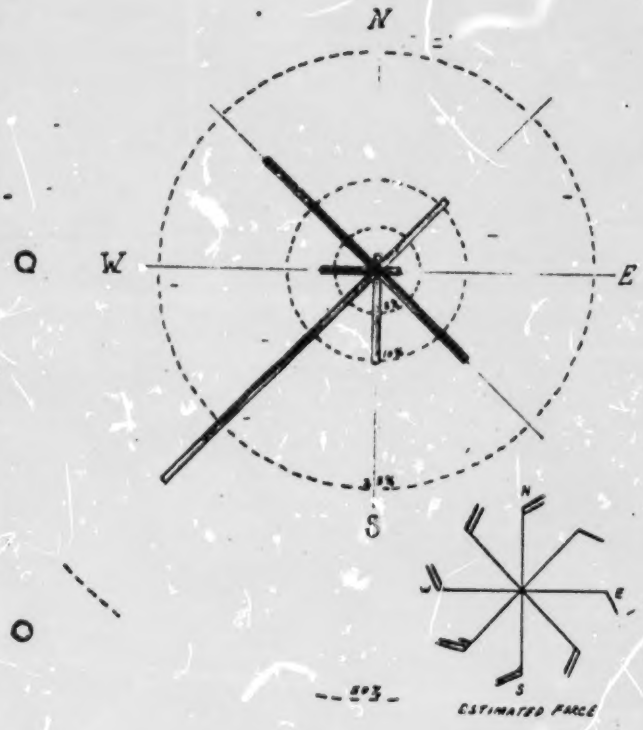

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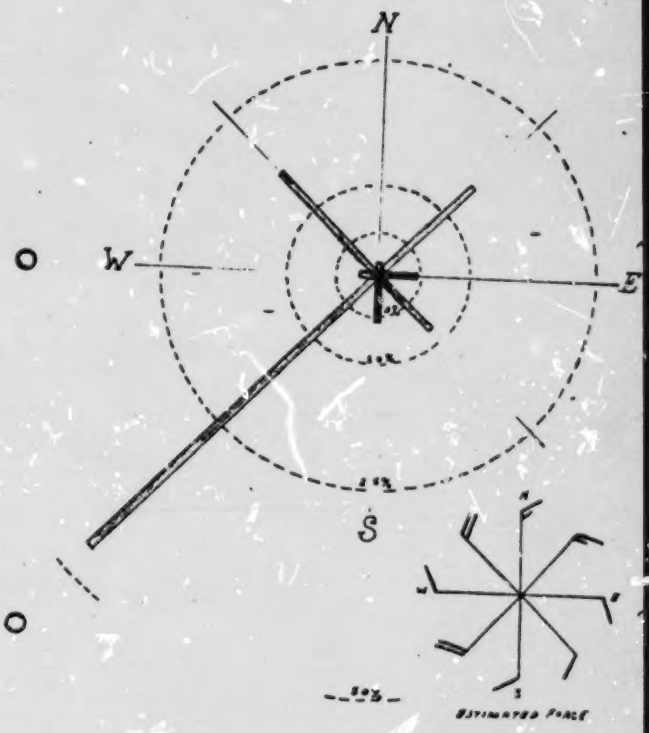

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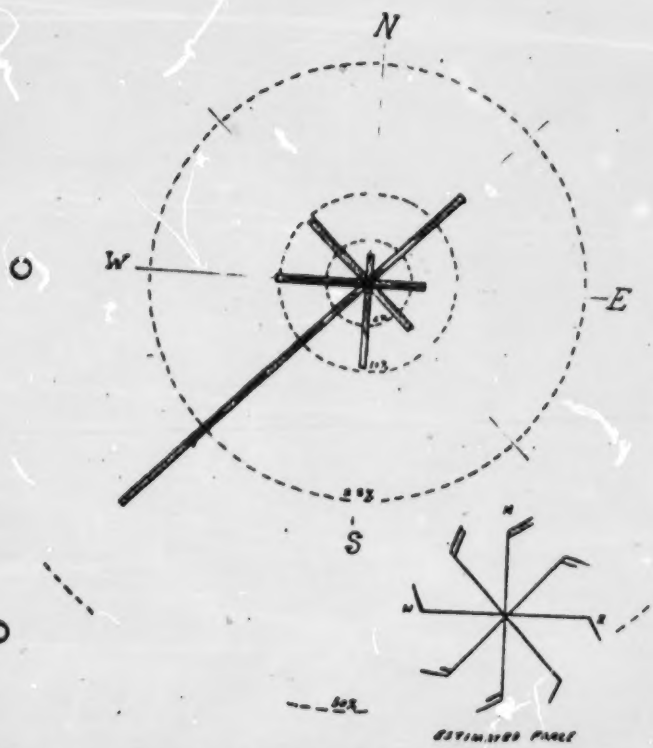

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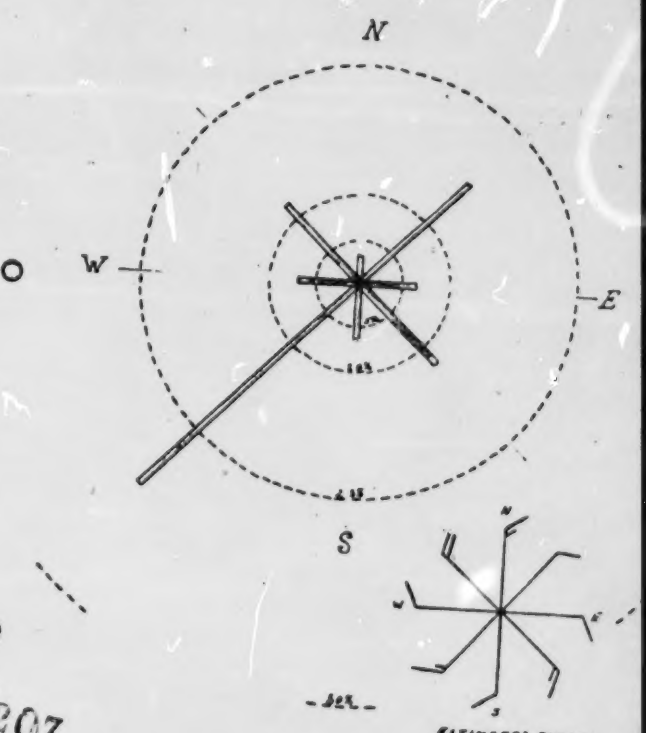

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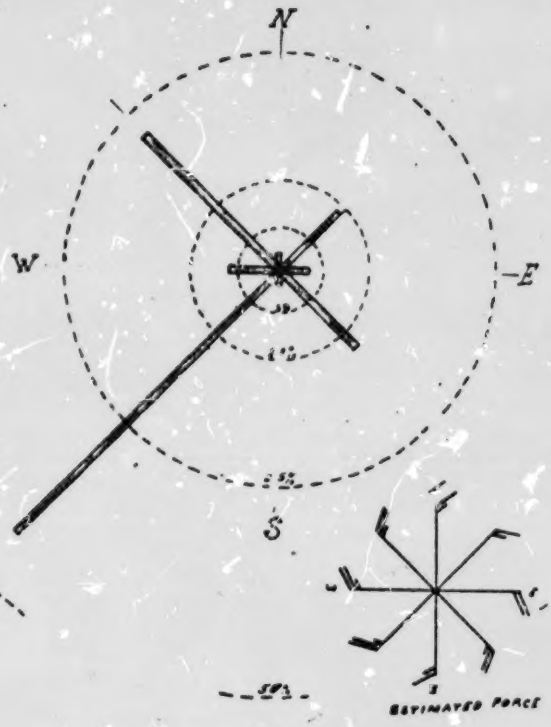

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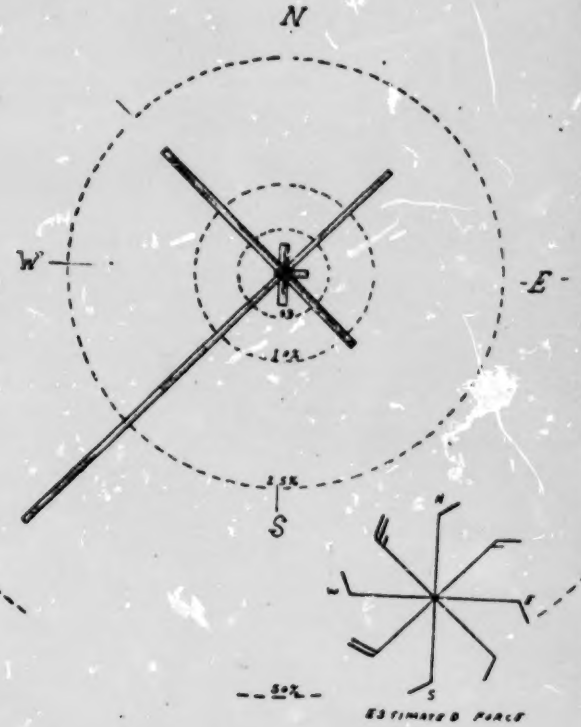

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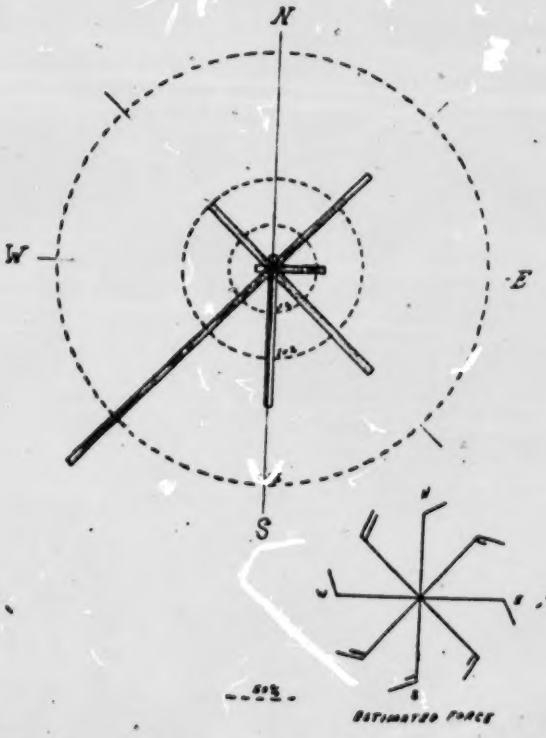
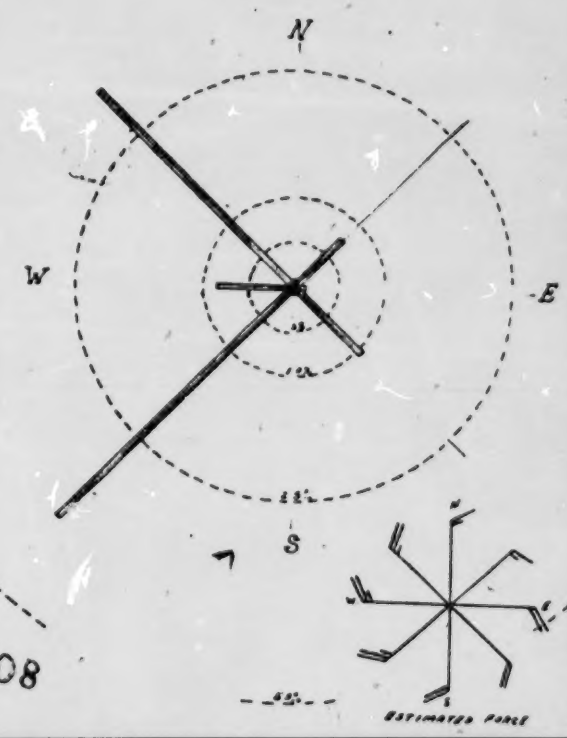


DECEMBER



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APPENDIX 2

Elektro Model WVG50G Complete Wind Electric System

Cost of Equipment Including F.O.B. to Boston, Mass.	$8,180.00
Freight Costs From Boston to State College, Pa.	$ 197.00
Maintenance Costs For a 15 Yr. Period	$1,200.00
Total Cost in 15 Yr. Period	$9,577.00

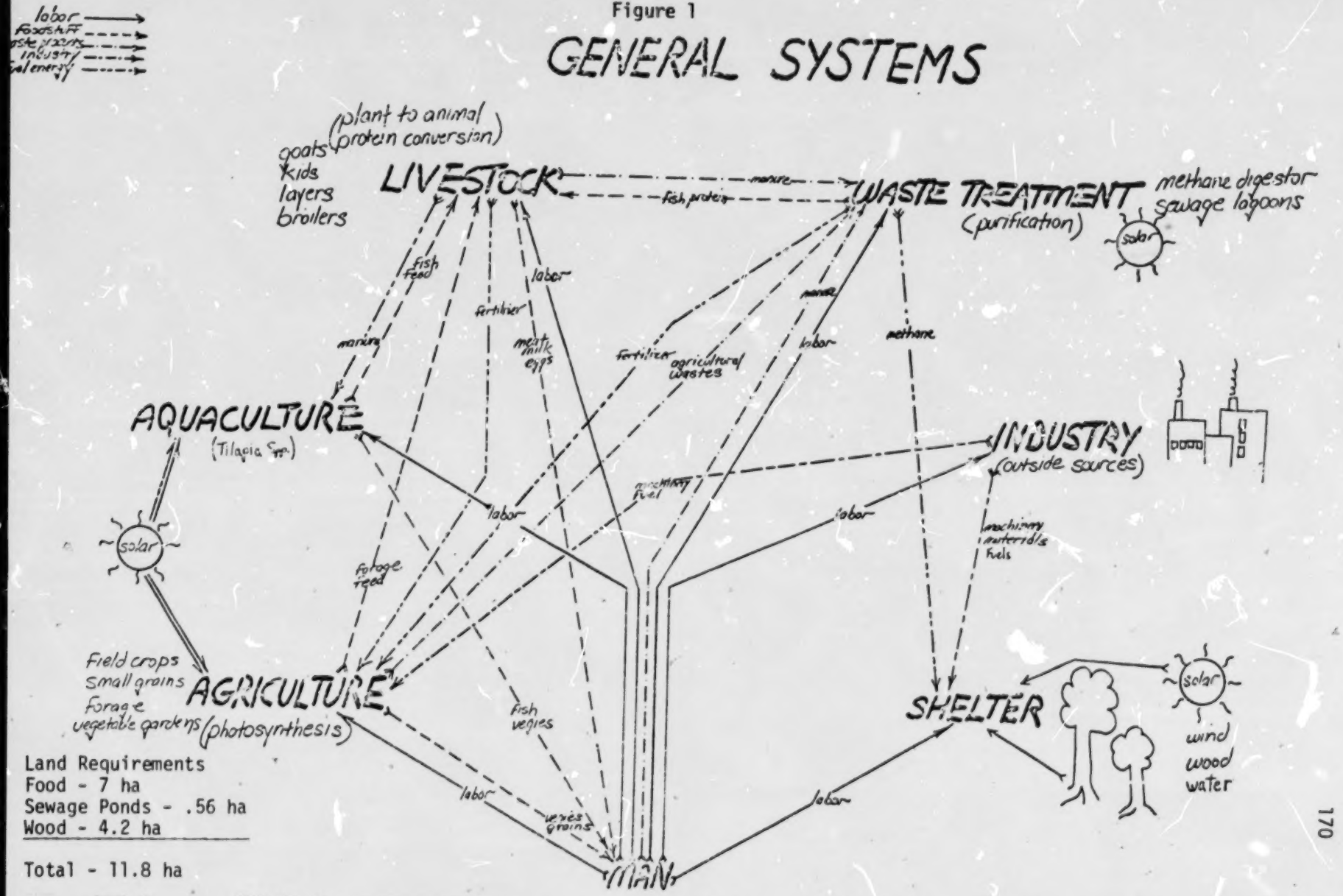
Number of Kilowatt Hours Expected to be Produced During the 15 Yr. Period	300 Kwhr/Month 3600 Kwhr/Year 54,000 Kwhr/15 Years

$$\text{Cost/Kilowatt Hour} = \frac{\$9577.00/15 \text{ Years}}{54{,}000 \text{ Kwhr}/15 \text{ Yrs.}}$$

Cost/Kilowatt Hour = 17.7 ¢

Figure 1

GENERAL SYSTEMS



Land Requirements
Food - 7 ha
Sewage Ponds - .56 ha
Wood - 4.2 ha

Total - 11.8 ha

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GENERAL SUMMARY AND CONCLUSIONS

Shelter - the building as designed and analyzed has a relatively low fuel requirement, but modifications in the design and analysis procedures are needed to improve and more completely evaluate the shelter. The best strategy for developing low-energy shelter, is by minimizing operating requirements: reduced space, adapted forms, adequate insulation, minimal internal temperatures, minimal use of sophisticated, capital inputs, etc. Utilization of solar space heating systems is restricted by the local climatic conditions (Central PA). Wood may be a very feasible supply of renewable fuel for this area (Northeast deciduous forest).

Food - the designed system provides 65% of the community's caloric and 200% of the protein requirements from an area of 7 hectares. The high labor requirements/unit area, would be low/person when handled by the total community. Modifications in the production components, i.e. increased utilization of intensive systems (e.g. greenhouse aquaculture), and in the machinery inputs, i.e. intermediate levels of mechanization, are needed to increase the efficiency of the system for all inputs. Attempting to supply contemporary food habits by a semi-autonomous system reduces efficiency, and for many foods it would be impractical (cooking oil, etc.). Contemporary food habits need to be modified to achieve higher efficiency, but this need for production efficiency must be balanced with the social and psychological importance of food consumption.

Wastes - incorporating the organic wastes system with food and energy production makes these wastes into community assets. It also allows the

costs of waste treatment to be divided between all the systems. Further investigation is needed on the capital and operating requirements, and sanitary characteristics of the designed system.

Energy and Water Use - the amounts of energy and water the community requires can be significantly reduced by the use of conservation technologies and changes in the members' lifestyles. Utilizing cooperative living to minimize consumption must be balanced with the needs for personal privacy and flexibility.

Education and Research - members living and working in a community such as presented in this project, would have a unique learning situation. They would become more aware of the resources required for everyday living, learn new skills and habits for reducing consumption, and develop the ability to function in group activities and decisions. The social and technological support systems of the community, would be well adapted to various interdisciplinary investigations for increasing resource (materials, energy, and human) efficiency. Figure 1 is a diagram of the overall community design.

In general, three basic strategies were utilized to reduce resource requirements: simplification, cooperation and integration. Initially, resource needs were simplified to reduce the resources required, e.g. reduced space, water, and appliance use, simpler diet, etc. Requirements were further reduced by the use of cooperative living arrangements, e.g. common dining, bathing, and laundry facilities, which allows multiple-use of machinery required and reduces duplicated efforts. Finally, the various service systems, shelter, food, waste, energy, and water, were designed as an integrated system to also maximize multiple and efficient use of resources.

The community described in this project is only a preliminary design. Much more in depth study is needed on all aspects of the system. The particular characteristics and performance of each component alone, and integrated into a system, need to be investigated: estimated capital and operating costs, cost/benefit analysis for varying organizational scales and degrees of autonomous operation, flexibility of the system(s) to fluctuating environmental and social conditions and situations, resulting resource and labor requirements from different levels of cooperative activity, etc.

Our main goal in designing a semi-autonomous community, was not to totally eliminate the need for industrial produced inputs (obviously, the system as designed could not even be conceived without the availability of many industrially produced materials and technologies), but to possibly develop efficient ways of utilizing these inputs. The concept of semi-autonomy and the strategies we utilized to achieve this (simplification, cooperation, and integration), could all be utilized, in modified forms, to help reduce consumption and increase efficiency of resource use.

Adopting simpler consumption habits on a broad scale could greatly reduce resource requirements (eating less meat, using fewer appliances, smaller cars, etc.). Developing cooperative social organizations to handle various domestic activities, could increase distribution efficiency of goods and services, and reduce overall labor requirements. For example, buying necessary inputs, fuel, tools, foodstuffs, paper, soaps, etc. in bulk quantities, would reduce packaging, handling and retailing costs; providing group utilization of machinery, e.g. woodworking and automotive tools, looms, laundry facilities, local energy technologies, farming machinery, etc., allows the costs to be distributed among many users, more effective utilization

of the machinery's productive capacities, and access to technologies that would be unaffordable on an individual owning basis (food storage facilities, quality electronics, etc.). Cooperative utilization could allow each unit of resource to support more people.

The total concept of integrated, semi-autonomous systems could be used for specialized communities other than a living/learning center, e.g. labor intensive light manufacturing (textiles, printing, information processing, etc.), intensive commercial agriculture, specialized skills and information centers, physical and psychological therapy communities, etc. Modified forms of this concept could be applied to existing and proposed housing developments, i.e. apartment and condominium complexes, urban and suburban neighborhoods. By adopting "self-sufficient" technologies (backyard food production, local energy supplies, etc.) and cooperative social organizations (food buying co-ops, child day care centers, auto maintenance garages, etc.), people in existing communities of the major metropolitan regions, could become more self-reliant and adapt themselves to a low energy and monetary growth economy.

Attempting to supply domestic resource requirements from local resources, has illustrated to us the extreme dependence of our present lifestyles on supplies of inexpensive, high quality material and energy resources. It has become apparent during our investigations, that the evolution of suitable social structures and values needed to accomodate minimum resource consumption lifestyles (whatever their form) is more important and necessary than the physical design of domestic systems.